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VERTOL DIVISION BOEING

BOEING-VERTOL Letter No. 61 2631

Date: May 25, 1961

To: Research Contracting Officer
U. S. Army Transportation Research Command
Transportation Corps
Fort Eustis, Virginia

Subject: Contract DA-44-177-TC-550 - Distribution of Abstract Pages for Volume I, TREC 60-64 and Volume II, TREC 60-65

Enclosure:
(1) Thirty (30) Copies of Abstract Page for Volume I, TREC 60-64
(2) Thirty (30) Copies of Abstract Page for Volume II, TREC 60-65
(3) Distribution List to Which Subject Reports Were Forwarded

Vertol Division, The Boeing Company, submitted to TRECOM and designated addressees, Reports, Volume I - TREC 60-64 and Volume II - TREC 60-65 entitled "Wind Tunnel Test and Further Analysis of Floating Wing Fuel Tanks for Helicopter Range Extension".

Submitted are the abstract pages for TREC 60-64, Enclosure (1), and TREC 60-65, Enclosure (2), in accordance with U. S. Army Transportation Research Circular 715-10, "Guide for the Preparation of Contractual Reports".

In addition, copies of the abstract pages for TREC 60-64 and TREC 60-65 are hereby distributed to the addressees listed on Enclosure (3).

VERTOL DIVISION
THE BOEING COMPANY

Robert E Tingley
Robert E. Tingley
Chief, Aircraft Contracts

RET/eab

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TREC 60-64

Vertol Division, Boeing Airplane Company, Morton, Pa., WIND TUNNEL TEST AND FURTHER ANALYSIS OF FLOATING WING FUEL TANKS FOR HELICOPTER RANGE EXTENSION, VOL. 1 - HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY, by R. B. Johnstone and C. B. Fay, October 1960. 145 pp incl. illus., tables
Contract (DA44-177-TC-550)

Unclassified Report

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I. Helicopter Range Extension - Wind Tunnel Study

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U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

TREC 60-64

WIND TUNNEL TESTS AND FURTHER ANALYSIS OF THE FLOATING WING FUEL TANKS FOR HELICOPTER RANGE EXTENSION

Volume 1

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

October 1960

R-204

prepared by :

VERTOL DIVISION
BOEING AIRPLANE COMPANY
Morton, Pennsylvania

WIND TUNNEL TEST AND FURTHER
ANALYSIS OF FLOATING WING
FUEL TANKS FOR HELICOPTER
RANGE EXTENSION
VOL. 1 - HELICOPTER RANGE EXTENSION
WIND TUNNEL STUDY

VERTOL DIVISION

BOEING AIRPLANE COMPANY

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PREPARED BY C. B. Fay *C. B. Fay* R. B. Johnstone *R. B. Johnstone*	REPORT NO. R-204 | NO. OF PAGES 145
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APPROVED BY J. Mallen *J. Mallen*	CONTRACT NO. DA44-177-TC-550 | ITEM NO.
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HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

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I. SUMMARY

A wind tunnel test has been conducted on a model helicopter fitted with floating wing fuel tanks for ferry range extension. The model consists of a tandem rotor helicopter with 3.9 ft. diameter electrically powered rotors mounted on a HUP (H-25) configured fuselage. Floating wing fuel tanks of an overall span of 4.7 ft. are attached to the fuselage through a skewed hinge.

The objectives of the wind tunnel test were:

(1) To determine the effect of the wing on the total rotor power and the rotor power distribution.

(2) To determine the stability characteristics of the floating wing and its effect on the stability of the system.

(3) To determine the feasibility of jettisoning the floating wing panels.

Qualitatively, the test proved the excellent behavior of the hinged wing panels at all operational speeds and attitudes, in and out of ground effect. Quantitatively, the results show that:

(1) The effect on induced power on the front and rear rotor due to the presence of the fuel wing was of the same magnitude as that predicted in the theoretical analysis and in the feasibility study.

(2) The stability characteristics of the fuel-wing were better than that predicted, which, in turn, will improve the stability and dynamic characteristics of the total system.

(3) The trajectory of the jettisoned wing panel was below the helicopter rotors, which is required if jettisoning the wing is to be used in the event of an emergency.

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II. PURPOSE OF THE WIND TUNNEL TEST

In general, the purpose of the helicopter range extension wind tunnel test is to substantiate the feasibility of using floating wing fuel tanks for helicopter range extension. Specifically, the objectives of the test are as follows:

(1) To determine the effect on induced power on the front and rear rotors due to the presence of the fuel wing.

(2) To determine the stability characteristics of the floating wing fuel tank in and out of ground effect.

(3) To determine the changes in stability characteristics of the helicopter with fuel wing tanks.

(4) To determine the trajectory of jettisoned wing relative to the helicopter model.

Presently, Vertol is using an IBM program to calculate the range, control positions and attitude of helicopters using the floating wing fuel tank. The program accounts for the wing effect on the rear rotor by adding the wing's downwash angle to the rotor inflow angle. The downwash angle is theoretically calculated as a function of wing loading and wing quarter chord position relative to the rear rotor hub. The program accounts for the forward rotor's effect on the wing by calculating the wing's local angle of attack as a function of the forward rotor's induced velocity. The induced velocity at the quarter chord is based on electromagnetic analog data. The resultant induced angle on the wing is based on the spanwise average of the rotor induced velocity. It is assumed that the wing does not affect the front rotor and that the rear rotor does not affect the wing. The wind tunnel results will verify the validity of the assumptions and the accuracy of the analysis.

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III. PROCEDURE

The wind tunnel program can be divided into four (4) major categories:

A. Induced Power Effect

B. Stability of Fuel Wing

C. Stability Effect of Wing

D. Jettisoned Wing Panel Trajectory

The procedure for obtaining information in each of these categories is outlined below:

A. Induced Power Effect

1. The power input to the forward and rear rotor for both the wing-on and wing-off configuration was recorded. The difference in rotor power between the two configurations while developing the same thrust on the relative rotors is due to the presence of the wing.

2. At three helicopter speeds and three associated attitudes, the thrust and power of each rotor was recorded for four sets of collective pitch. For each of two front rotor collective pitch settings, the rear rotor was tested at two pitch settings. Thrust of the front rotor can be plotted vs. collective pitch, assuming a linear variation. Thrust of the rear rotor can likewise be plotted at constant values of front rotor collective. Similarly the power can be plotted, assuming that power varies linearly with thrust.

3. These plots can be used to determine the power required of each rotor while developing the same thrust with wing-on as with wing-off. The difference in power can be attributed to the influence of the wing.

B. Stability of Fuel Wing

1. The wing panel response to a step input was recorded to determine the damping ratio and natural frequency, assuming the wing responds as a second order system. The variation of these dynamic parameters with wing loading and speed was determined.

2. The wing action was observed as the wing became self-supporting aerodynamically with increasing speed in ground effect.

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C. Stability Effect of Wing on Helicopter

1. From each of several assumed equilibrium positions of the system, the changes in pitching moments with angle of attack and speed were recorded. It is assumed that the resulting stability derivatives are symmetric about the trim point and linear for $\pm 3^{\circ}$ and ± 5 to 10 knots.

2. The difference in the stability characteristics between the wing-off and wing-on configurations at the same trim speed, attitude and control settings can be attributed to the influence of the wing.

D. Jettisoned Wing Panel Trajectory

1. From one assumed model attitude and speed, one wing panel of the wood wing set was jettisoned. The initial test was conducted with rotor blades removed. The path of the wing panel relative to the model was recorded from both the side and rear view with high speed cameras.

2. After determining from the above test the possibility of the wing panel trajectory passing through the helicopter rotors, the jettison test was repeated with rotor blades installed. One wood panel and one metal panel each were jettisoned twice.

A detailed test program of the Helicopter Range Extension System is enclosed as Appendix A. The tunnel test velocities of 30, 70 and 85 knots represent the landing, take-off and cruising speeds, respectively. It should be noted that the test points involving the metal wing were run at 85 and 90 knots only. The metal wing would not support itself due to Reynolds' number, presence of rotor, etc., at speeds lower than 85 knots. The range of attitudes tested was selected to include the trim attitude of both the basic helicopter and helicopter-with-wing configuration.

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IV. DESCRIPTION OF THE POWERED HELICOPTER RANGE EXTENSION MODEL AND SUPPORTING EQUIPMENT

An HUP model helicopter was built by David Taylor Model Basin in 1956. The model is owned by the Navy but is currently bailed to the Army for the range extension contract. The rotors are dynamically similar, powered and individually adjustable for both cyclic and collective pitch. Lift is measured at each rotor by means of self-contained strain gaged flexual links. Rotor drag and side loads, as well as hub moments, are also measured by strain gage flexures. Through the Range Extension Contract, a torque measuring system has been designed and built to measure torque at each rotor.

The fuselage consists of a hollow plastic shell, molded to the contour of the XHJP-1.

The rotor blades have tubular stainless steel spars with balsa wood laminations and pine trailing edges. The blades are covered with two layers of silk opposed at 45°. They are mass balanced. The mass of the model blade is (scale factor)^3 of the mass of the full scale blade, which is required to simulate the same coning angles of the full scale rotor at the same tip speed.

The model motor was borrowed from DTMB for the Range Extension Test. It is a 30 HP electric, 400 cycle, variable frequency, water-cooled motor. The rotors are belt driven, using Gilmer timing belts, from right angle gear boxes attached to the double-ended motor. The gear ratio between the motor and rotor is 2.17 to 1.

Two sets of hinged wings were designed and built with remotely adjustable trailing edge flaps. The wing panels were made of wood and metal to simulate the "wing tanks empty" and "wing tanks full" conditions, respectively. The wing panels are attached to the wing stub through a skewed hinge. The stub extends through the fuselage shell and is bolted to the model frame. The trailing edge flap position and the wing panel attitude position about the hinge are measured by means of potentiometers.

The model contained a pitch actuator mounted in the fuselage which in turn was mounted on a single strut in the wind tunnel test section.

All strain gage flexure data and wing panel attitude positions were recorded on Speedomax recorders. The wing panel dynamic response was recorded on an electronic Brush recorder. Motion and still cameras were positioned behind and to the side of the model to give complete visual coverage throughout the wind tunnel tests.

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Dimensions and other characteristics of the powered model are as follows:

Rotor speed (maximum continuous)	300 rpm
Rotor diameter	3.89 ft.
Rotor solidity	.059
Fuselage length	3.55 ft.
Overall length (rotors turning)	6.33 ft.
Distance between rotors	2.44 ft.
Rotor design thrust (each)	33.3 lb.
Wing span	4.67 ft.
Wing hinge skew angle	45°
Wing loading	
wooden wing	3.0 lb./ft.^{2}
metal wing	21.9 lb./ft.^{2}

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V. DISCUSSION OF TEST RESULTS

A. Outline of Discussion

The wind tunnel test of the range extension model was conducted to investigate three basic characteristics of the concept. These are:

(1) The effect of the wing on the total rotor power and the rotor power distribution.

(2) The stability characteristics of the floating wing and its effect on the stability of the system.

(3) The feasibility of jettisoning the floating wing panels.

All test results are discussed so as to show a comparison between the basic helicopter and the wing-helicopter configuration. Further comparison is made between the initial cruise condition of the system, with a relatively high wing loading, and the final cruise condition, with a light wing loading.

B. Accuracy of Results

The individual rotor strain gaged data were recorded on Brown Speedomax pen recorders. Calibration curves for the rotor lift, drag, pitching moment, torque, trailing edge flap position, wing attitude and fuselage attitude are presented in Figures 1 through 11. Due to sensitivity of recorders and variation of loads while recording data, there will be some errors introduced into the data which can be designated as read-out errors. As a consequence, the data are accurate only within certain degrees as shown in Table 1. The relative lack of sensitivity of the aft rotor torque was due basically to poor brush pressure on the aft rotor torque slip-rings. As a result, the recorded data appeared as a band rather than a well defined trace.

During the tests, four sets of rotor collective pitch were investigated. After the test, the collective pitch was recalibrated, using optical equipment including a transit and level. The calibration showed that there was a discrepancy between the indicated pitch setting and the actual. It should be noted that throughout this report, the collective pitch data have been corrected to the actual pitch setting, using the calibration data tabulated below.

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COLLECTIVE PITCH CALIBRATION DATA

Indicated		Corrected	
Fwd (deg.)	Aft (deg.)	Fwd (deg.)	Aft (deg.)
7	9	6.8	7.5
10	9	9.05	7.5
10	12	9.05	10
7	12	6.8	10

In order to verify the accuracy of the model rotor thrust measuring system, the sum of the forward and rear rotor thrust was compared to the tunnel balance data for the basic helicopter configuration. Figure 13 presents the vertical component of the model thrust plotted versus the vertical force measured on the tunnel balance. The figure shows excellent correlation between the two independent means of measurements.

The validity of the individual rotor thrust was checked by comparing the measured data to that calculated at the same speed. The theoretical variation of thrust with collective pitch and angle of attack at various speeds for both the forward and rear rotor is presented in Figures 14 to 24. The calculation included the effects of the rotor mutual interference associated with the tandem configuration. The deviation of the the theoretical thrust for both forward and rear rotor is shown in Appendix B. The test data are also presented in these figures and, in general, show good correlation with the theory. The apparent discrepancy in some of the rotor thrust data is probably due to the inaccuracy of the recalibrated collective pitch instrumentation, as well as rotor blade flexibility.

Standard wall corrections used for normal wind tunnel tests were applied to the wind tunnel balance readings, based on the information presented in reference 2. Detailed discussion of these corrections is included in the University of Maryland Wind Tunnel Report No. 278, presented in this report as Appendix D.

No tunnel wall corrections were applied to the individual rotor data. Since the rotor data are compared at the same thrust, standard wall corrections would be similar, if not identical, for each data point. The corrections would cancel when the helicopter-wing configuration data were presented as a percentage of the corresponding basic helicopter data.

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C. The Effect of the Wing on Rotor Power

The floating wing in the presence of the helicopter will have certain effects on the rotor inflow as well as the drag power of the aircraft. The additional inflow through the rotors due to the induced velocity of the wing will influence the rotor power required. The magnitude of the interference power could affect the feasibility of the floating wing concept. To determine the influence of the wing on the rotor, the wind tunnel model power required was recorded at various speeds, attitudes and disc loadings, with and without the wing. By obtaining the change in individual rotor power of the helicopter with the addition of the wing at the same speed, disc loading and attitude, the magnitude of the wing-rotor interference power was determined.

In order to obtain tunnel data at a common disc loading, thrust and rotor power were plotted against rotor collective pitch, as shown in Figure 25 through 43. Each figure represents a specific speed, attitude and configuration. By entering these plots at a constant value of thrust, the individual rotor power at each speed, disc loading and attitude and for both the wing-helicopter and basic helicopter configurations can be determined. The change in rotor power is obtained by subtracting the power for the wing-helicopter configuration from the basic helicopter rotor power at the same speed and attitude. Any difference in rotor power is attributed to the influence of the fuel-wing on the helicopter rotors.

Each curve in Figure 25 through 43 was developed by drawing straight lines between two test points. It can be shown theoretically that thrust varies linearly with rotor collective pitch. Similarly, it can be shown that rotor power varies nonlinearly with collective pitch. However, the theoretical variation of the slope of power versus collective pitch between the values of pitch tested is very small. Therefore, the straight line variation between the test points assumed for simplicity appears to be a valid assumption.

The power data were compared at a constant thrust of 32 pounds, which is approximately the design rotor thrust of the model. In Figures 44, 45 and 46 the forward, rear and total rotor power for the basic helicopter and wing-helicopter configurations are presented. The 45° line was drawn to separate the data that indicate an increase in power due to the wing interference from that data which show a decrease in power. Each data point is related to a specific speed, attitude and wing loading. Table 2 correlates the point number and the corresponding speed, attitude and wing loading.

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in Figure 44, the forward rotor plot indicates a slight increase in power required for the wing-helicopter configuration due to wing interference. The rear rotor data presented in Figure 45, show more scatter in the points than the forward rotor data, as might be expected. These data indicate that at the lower speeds, the rotor power decreases with the addition of the wing, but at the higher speeds, the power increased. The scatter represents a rear rotor power increment difference of 30% decrease to 15% increase. The interference effect of the wing on total power is shown in Figure 46. The total power scatter represents a power increment difference of 19% decrease to 15% increase.

Because of the expected increase in rotor power due to the additional inflow induced by the wing, the torque data for the rear rotor test points that indicate a decrease in power are questionable. Therefore, it is desirable to analyze the data using a different method of power measurement. The model motor electrical power input was recorded throughout the wind tunnel tests. By using the motor calibration curve and calculating the transmission efficiency, total rotor power may be obtained.

The motor calibration curve is presented in Figure 47. The gear box and belt transmission efficiencies were calculated to be 95% and 90% respectively. By correcting the torque for these efficiencies and applying the proper constant, the total rotor horsepower was computed from the motor data, and presented in Figure 46. The motor power data are higher in magnitude than the corresponding rotor torque data, indicating an increase in power for the helicopter-wing system due to wing-rotor interference.

To determine the effect on power for each rotor, the forward rotor torque data were assumed to be valid. The forward rotor torque data were subtracted from the total motor power data to obtain the rear rotor power. The rear rotor motor data are compared to the torque data in Figure 45.

An alternate method of measuring power was based on collective pitch. At a constant thrust, angle of attack, and speed; a correlation can be drawn between collective pitch and thrust horsepower. Since any change in collective pitch reflects a change in inflow which in turn is a function of horsepower, a change in collective pitch can be related directly to a change in horsepower. A complete analysis is presented in Appendix B. The increment of horsepower calculated from the change in collective pitch was added to the torque horsepower of the basic helicopter configuration to obtain rotor power for the helicopter-wing combination.

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In Figures 48 and 49, the forward and rear rotor powers based on collective pitch are compared with and without the wing. The forward rotor data indicates an increase in power due to the wing interference, especially at the higher speeds. The rear rotor data shows scatter, as well as a large power increment with the addition of the wing. The total increase in power, due to the wing interference is approximately 27%, as indicated in Figure 50.

Due to the inaccuracy of measuring collective pitch, as discussed above, and the theoretical basis of calculating the change in power, the power data based on collective pitch are undoubtedly the most unreliable of the three methods.

A summary indicating the effect of the wing lift on the total rotor horsepower is presented in Figure 51 for the three methods of measuring power. The limits of the band described by the data indicate a 20% decrease in power at one extreme and a 26% increase in power at the other. If the band was defined by the more reliable measured power, that is torque and motor power, the upper limit would be a 14% increase. Since this increase is of the magnitude accounted for in the analytical analysis of the floating wing fuel tank range extension system, the results of the interference power investigation substantiated the feasibility of the concept.

D. Stability Effect

The purposes of the second phase of the wind tunnel test were:

(1) To determine the stability characteristics of the floating fuel wing in and out of ground effect.

(2) To determine the change in the characteristics of the helicopter caused by the addition of the floating fuel wing.

Good damping characteristics and stable wing panel motion of the fuel wing were desirable.

In order to determine the wing's dynamic response, a vertical gust input was simulated by deflecting and releasing the wing at various speeds and angles of attack. The wing response was measured by a rotary slide wire position transducer installed in the hinge of the wing. The transducer was attached to a potentiometer which was connected to an amplifier. The amplifier was wired to an electronic Brush recorder.

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The wooden wing was tested at three different speeds to determine the effect of speed on the wing response. Three runs were performed at each speed to verify the results. One run was selected as a representative response for each speed. The amplitude was nondimensionalized and plotted versus time to illustrate the response of the wing (Figure 52). By comparing the wooden wing's response at various speeds, the wing's damping characteristics were seen to be a function of speed. The metal wing was tested at one speed and was plotted by the same method as the wooden wing. (See Figure 53).

The natural frequencies and damping ratios were measured at the various speeds and for the two configurations the damped frequencies were determined by measuring the periods of each cycle and then finding the average period for the entire run. By dividing the damped frequency by the square root of one minus the square of the damping ratio, the natural frequency was calculated. The damping ratio was measured by using a log-log plot of the relationship of the amplitude ratio to the damping ratio for the transient solution of a second-order differential equation with constant coefficients.

The theoretical natural frequency and damping ratios were calculated to compare theory with experiment. Assuming the wing panel behaves as a second order system, the damping ratio and natural frequency of the panel can be calculated from expressions derived in Appendix B.

The model dynamic characteristics are subject to a scale factor correction when converting the model values to full scale, as derived in Appendix B. The result is that the damping ratio of the full scale is three times that of the model and the natural frequency of the full scale is one-third that of the model. A comparison of the full scale value for calculated and measured data is shown in Table 3. It is obvious that calculated values of damping ratio were relatively low compared to the measured data. Hence the stability characteristics of the wing on the helicopter may be better than those shown in the feasibility study, as explained below.

During the aerodynamic phase of the feasibility study, the results of the dynamic response investigation indicated that the wing-helicopter system's response to gusts was favorable to the stability of the helicopter. The dynamic response study further indicated that if the wing damping were increased, the stability of the system would also increase. Since the damping characteristics of the model are better than that predicted by methods used in the feasibility study, the conclusion would be that the stability of the helicopter-wing system is at least as good as, and possibly better than, that predicted in the feasibility report.

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A comparison of the model stability derivatives was made between the no-wing and wing-helicopter configuration. The two stability derivatives that were calculated were C_{m_α}, which is a change in moment coefficient with respect to a change in attitude and C_{m_μ} which is a change in moment coefficient with respect to a change in advance ratio. To determine the stability derivative C_{m_μ} the helicopter attitude was held constant and the speed was varied. The moment was measured before and after the speed change. This moment was corrected for the moment due to differences between the thrust of the forward and rear rotors so that the fuselage and fuselage-with-wing moments could be calculated. The stability derivatives were calculated by dividing the change in advance ratio into the change in corrected moment coefficient. The same method was followed for C_{m_α}, except the speed was held constant and the helicopter's attitude was varied. Tables 4 and 5 are tabular presentations of the C_{m_α} and C_{m_μ} stability derivatives, respectively. However, due to the relatively large size of the fixed wing stub, it is felt that the data does not represent valid stability derivatives applicable to the full scale configuration.

The basic helicopter and the helicopter with wooden and metal wings were tested in ground effect to observe any changes in the wing panel performance due to the reflected upwash of the front rotor. The model was tested at speeds and attitudes corresponding to the take-off and landing conditions of the system. Since no changes in wing behavior were noticed, the conclusion was that the forward rotor upwash did not affect the wing.

E. Jettison of Wing

The third phase of the wind tunnel test was to determine the feasibility of jettisoning the wing in flight. The basic problem of jettisoning a lifting surface such as a wing is the potential danger of interference of the wing with the rotors. Both the metal and wooden wings were jettisoned to evaluate the trajectory of a full fuel wing and an empty fuel wing.

The wing was attached to the stub by means of a hinge. To jettison the wing, a trigger release actuated by a solenoid was used to disengage the pin from the hinge.

REV

From one assumed model attitude and speed, one wing panel of the wood wing set was jettisoned. The initial test was conducted with rotor blades removed. The path of the wing panel relative to the model was recorded from both the side and rear view with high speed cameras. After determining from the above test the path of the wing panel with respect to the helicopter rotors, the jettison test was repeated with the rotor blades installed. One wood panel and one metal panel were separately jettisoned twice.

The path of the wing panel relative to the model for the wood and metal wings are shown in Figure 54 and Figure 55, respectively. The wooden wing pitched up 90° and traveled up and back. The metal wing's tip dropped as the wing traveled straight back.

A movie titled "Helicopter Range Extension Wind Tunnel Tests", available on a loan basis from Vertol Division, Boeing Airplane Company, gives a complete review of the wing panels' trajectories, as well as the dynamic characteristics of the model wing fuel tank.

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VI. CONCLUSIONS

In reviewing the purposes of the wind tunnel tests and the results obtained, it is quite evident that the test has fulfilled its general purpose of substantiating the feasibility of using floating wing fuel tanks for helicopter range extension. Qualitatively, the test proved the predicted excellent behavior of the hinged panel at all speeds and attitudes, in and out of ground effect. Quantitatively, the results show that:

(1) The effect of induced power on the front and rear rotor due to the presence of the fuel wing was of the same magnitude as that predicted in the theoretical analysis and in the feasibility study.

(2) The stability characteristics of the fuel-wing were better than that predicted, which in turn will improve the stability and dynamic characteristics of the total system.

(3) The trajectory of the jettisoned wing panel was below the helicopter rotors, which is required if jettisoning the wing is to be used in the event of an emergency.

Since the results substantiate the validity of Vertol's methods of analyzing the helicopter-wing system, these same methods may be used in analyzing variations of parameters such as wing loading, rotor disc loading, speed, etc.

The next logical step in the development of the helicopter range extension system using floating wing fuel tanks is a detail design phase of a full scale wing to be tested and evaluated on a helicopter such as the H-21.

Through this positive approach to the solution of extended helicopter ferry range, the helicopter will eventually be capable of flying in a combat readiness condition to any point in the world with a minimum of structural modification and weight penalty.

REV

VII. REFERENCES AND BIBLIOGRAPHY

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REV

VIII. LIST OF FIGURES

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LIST OF FIGURES
(Continued)

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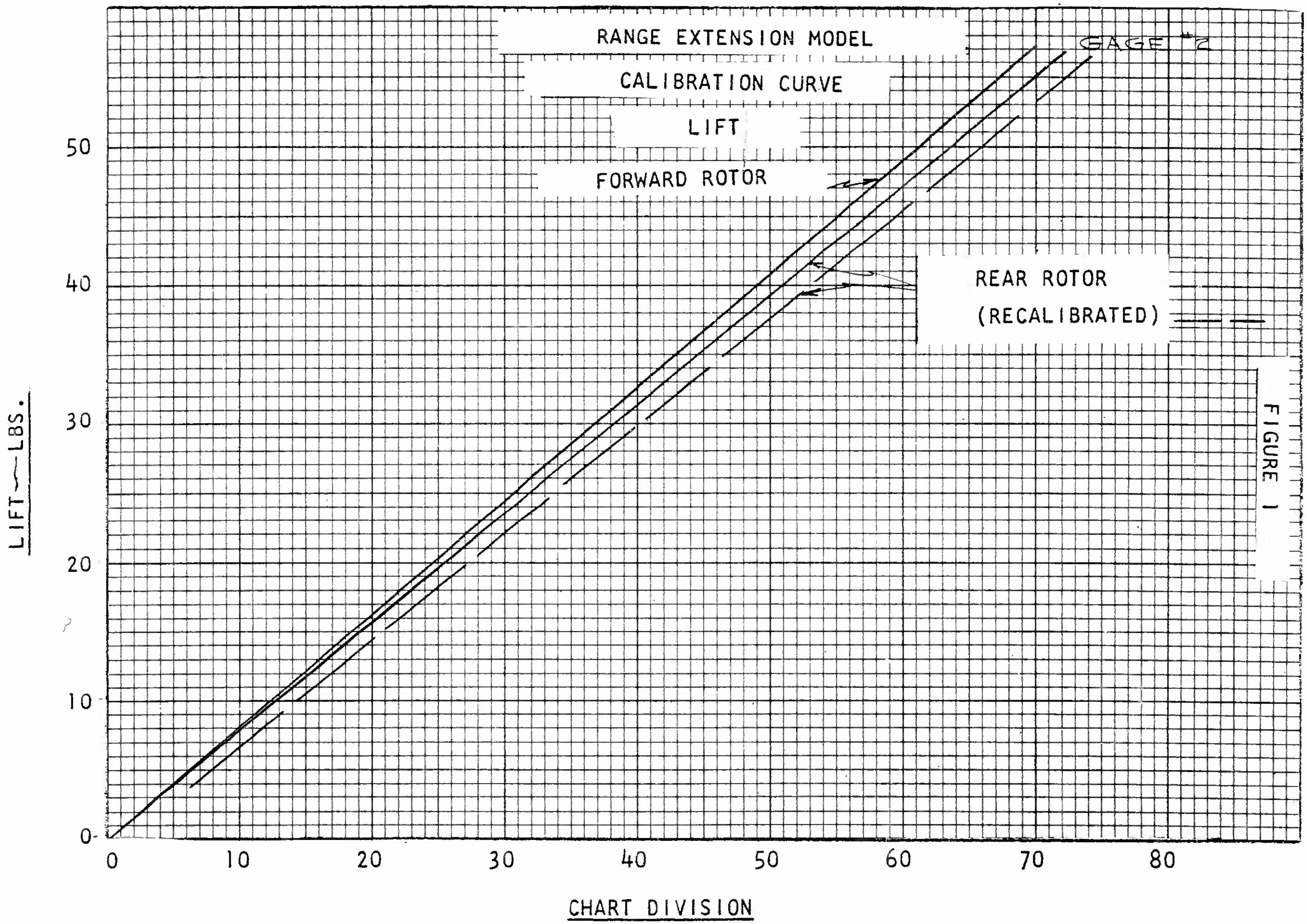

RANGE EXTENSION MODEL
CALIBRATION CURVE
LIFT
FORWARD ROTOR
REAR ROTOR
(RECALIBRATED)
GAGE #2
FIGURE 1
LIFT — LBS.
0
10
20
30
40
50
CHART DIVISION
0
10
20
30
40
50
60
70
80

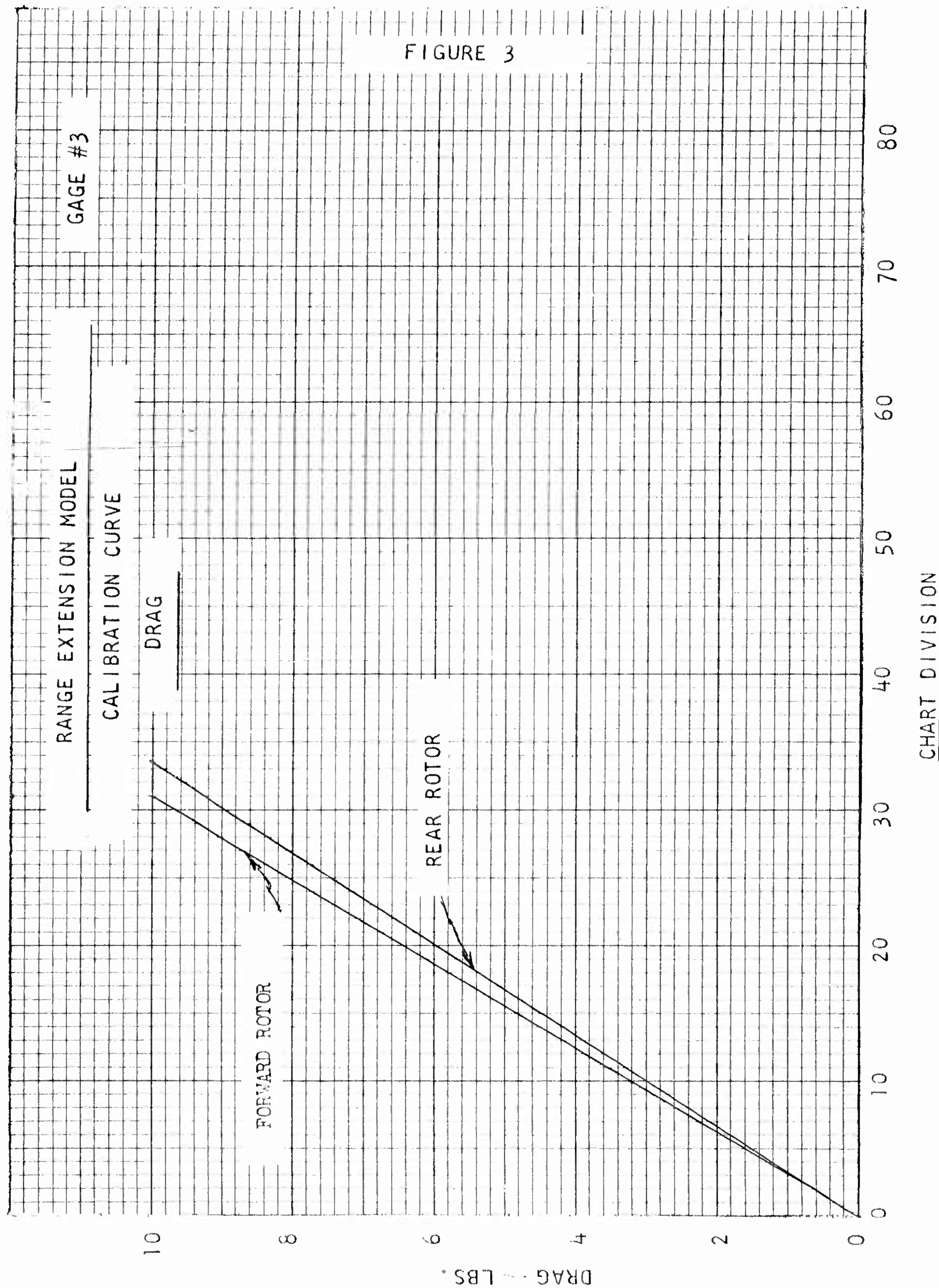

GAGE #3
RANGE EXTENSION MODEL
CALIBRATION CURVE
DRAG
REAR ROTOR
FORWARD ROTOR
CHART DIVISION
0
10
20
30
40
50
60
70
80
DRAG — LBS.
0
2
4
6
8
10

FIGURE 3

FIGURE 5

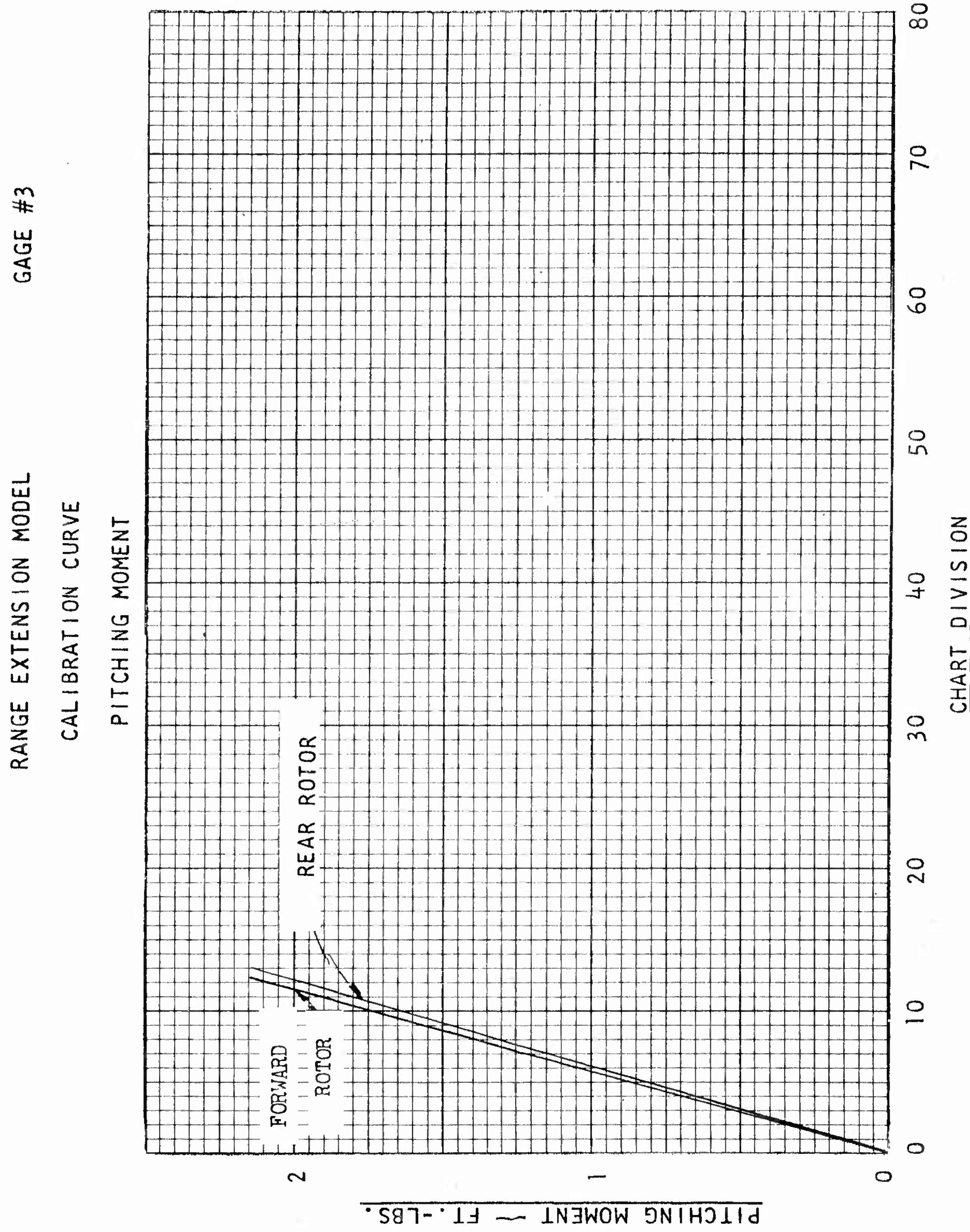

RANGE EXTENSION MODEL
CALIBRATION CURVE
PITCHING MOMENT
GAGE #3
REAR ROTOR
FORWARD ROTOR
0
10
20
30
40
50
60
70
80
CHART DIVISION
0
1
2
PITCHING MOMENT ~ FT.-LBS.

FIGURE 6

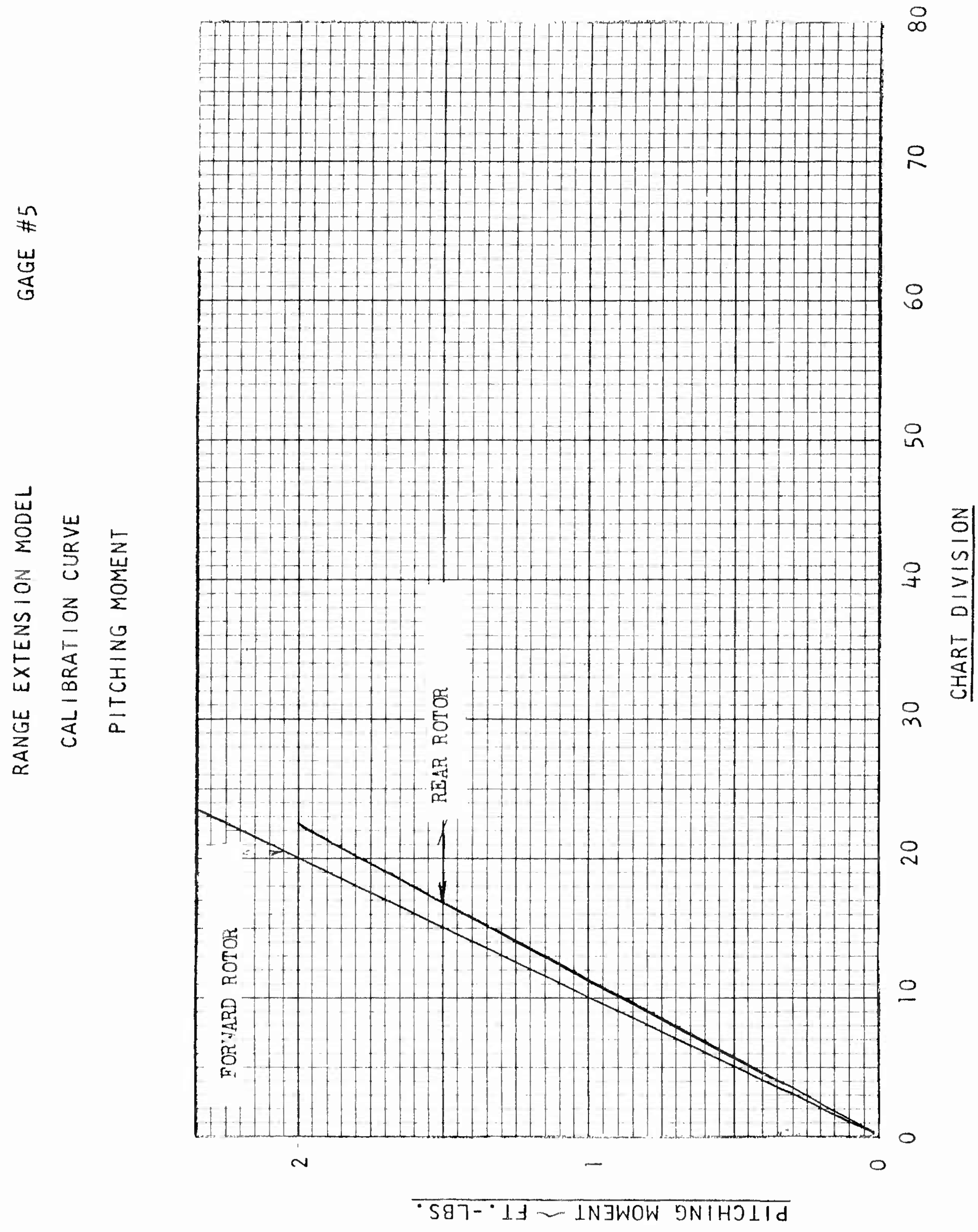

RANGE EXTENSION MODEL
CALIBRATION CURVE
PITCHING MOMENT
GAGE #5
FORWARD ROTOR
REAR ROTOR
0
10
20
30
40
50
60
70
80
CHART DIVISION
0
1
2
PITCHING MOMENT ~ FT.-LBS.

FIGURE 7

RANGE EXTENSION MODEL

CALIBRATION CURVE

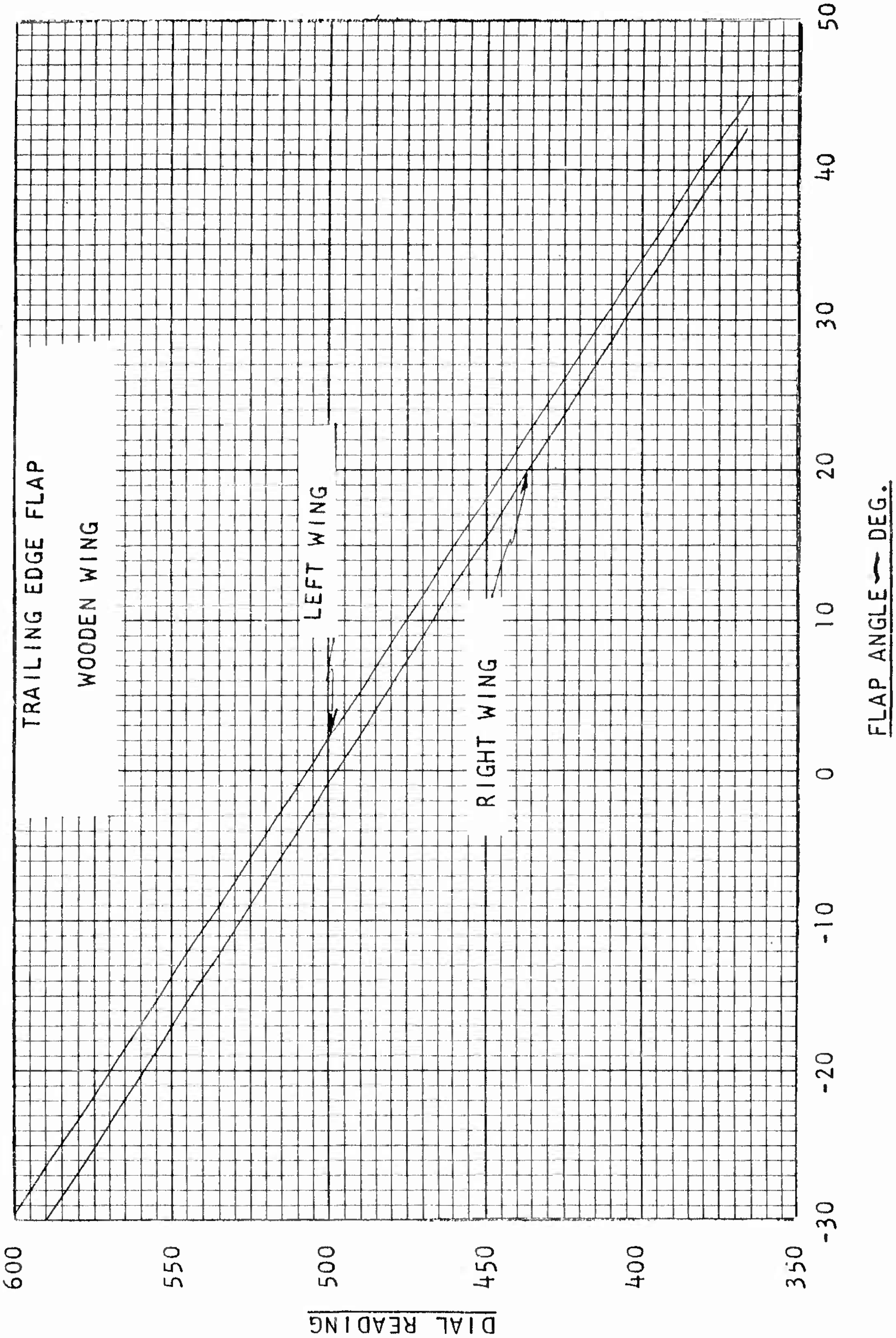


FIGURE 8

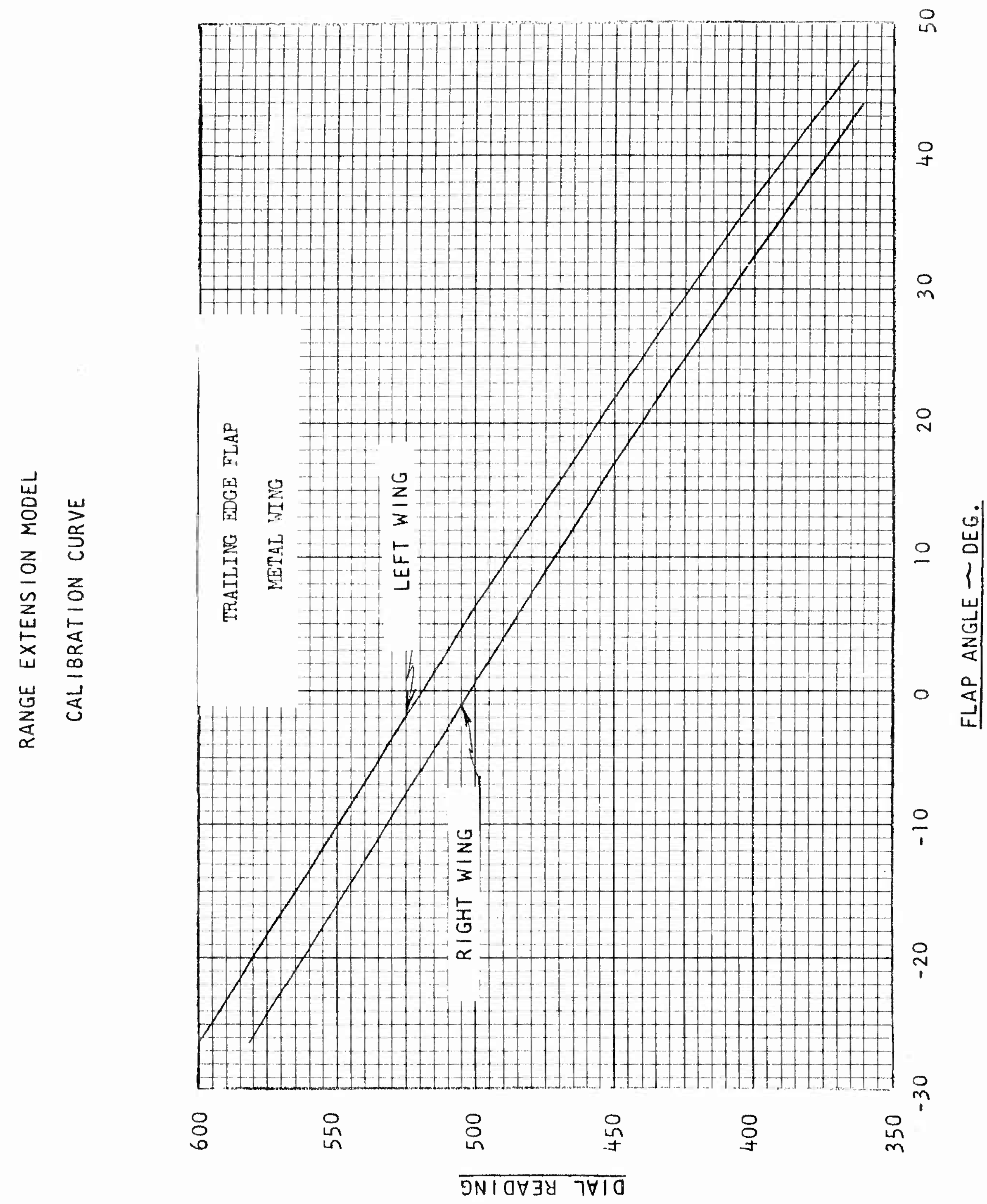

RANGE EXTENSION MODEL
CALIBRATION CURVE
TRAILING EDGE FLAP
METAL WING
LEFT WING
RIGHT WING
FLAP ANGLE ~ DEG.
-30
-20
-10
0
10
20
30
40
50
DIAL READING
600
550
500
450
400
350

FIGURE 9

RANGE EXTENSION MODEL

CALIBRATION CURVE

WING ATTITUDE

GAGE #0

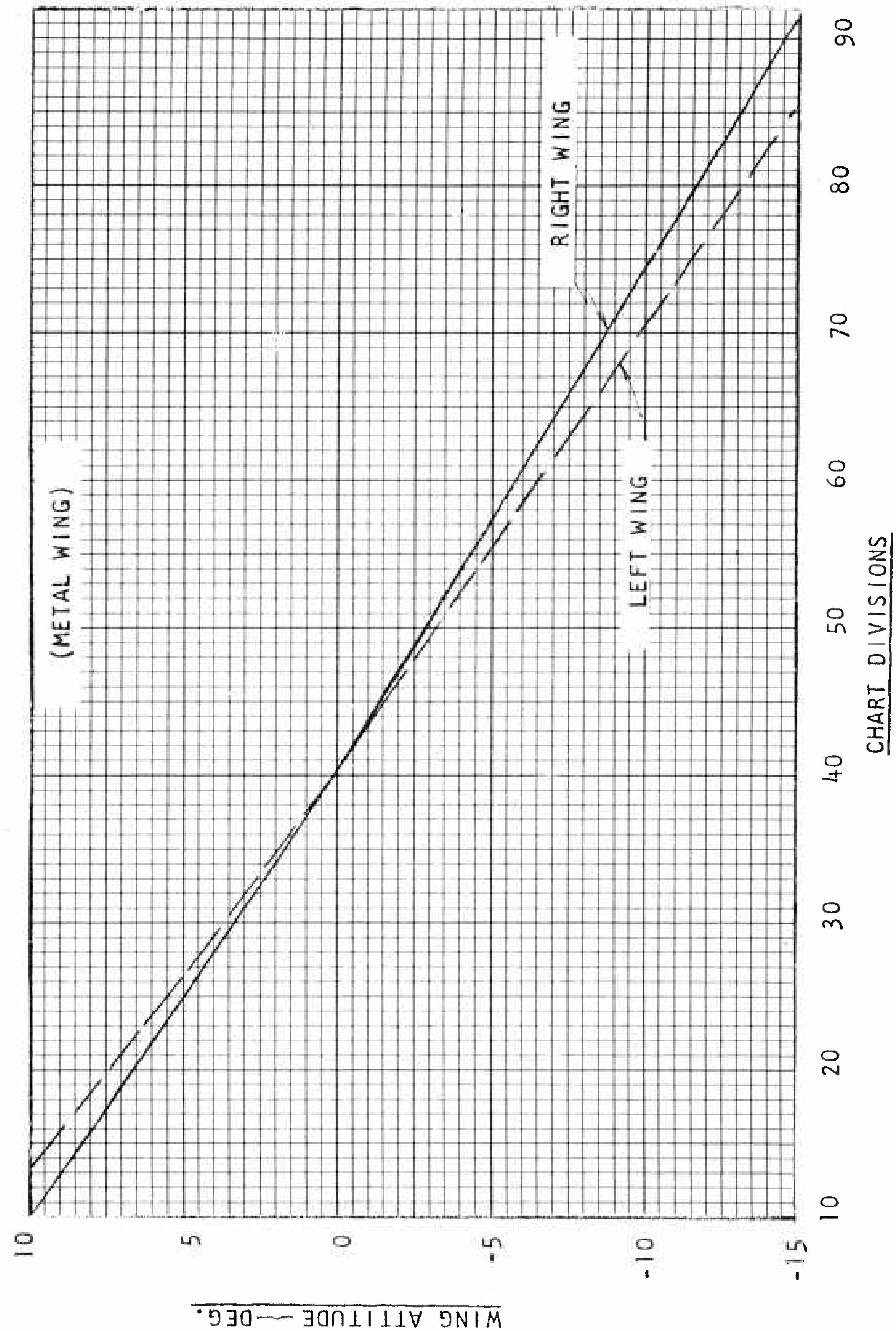


FIGURE 10

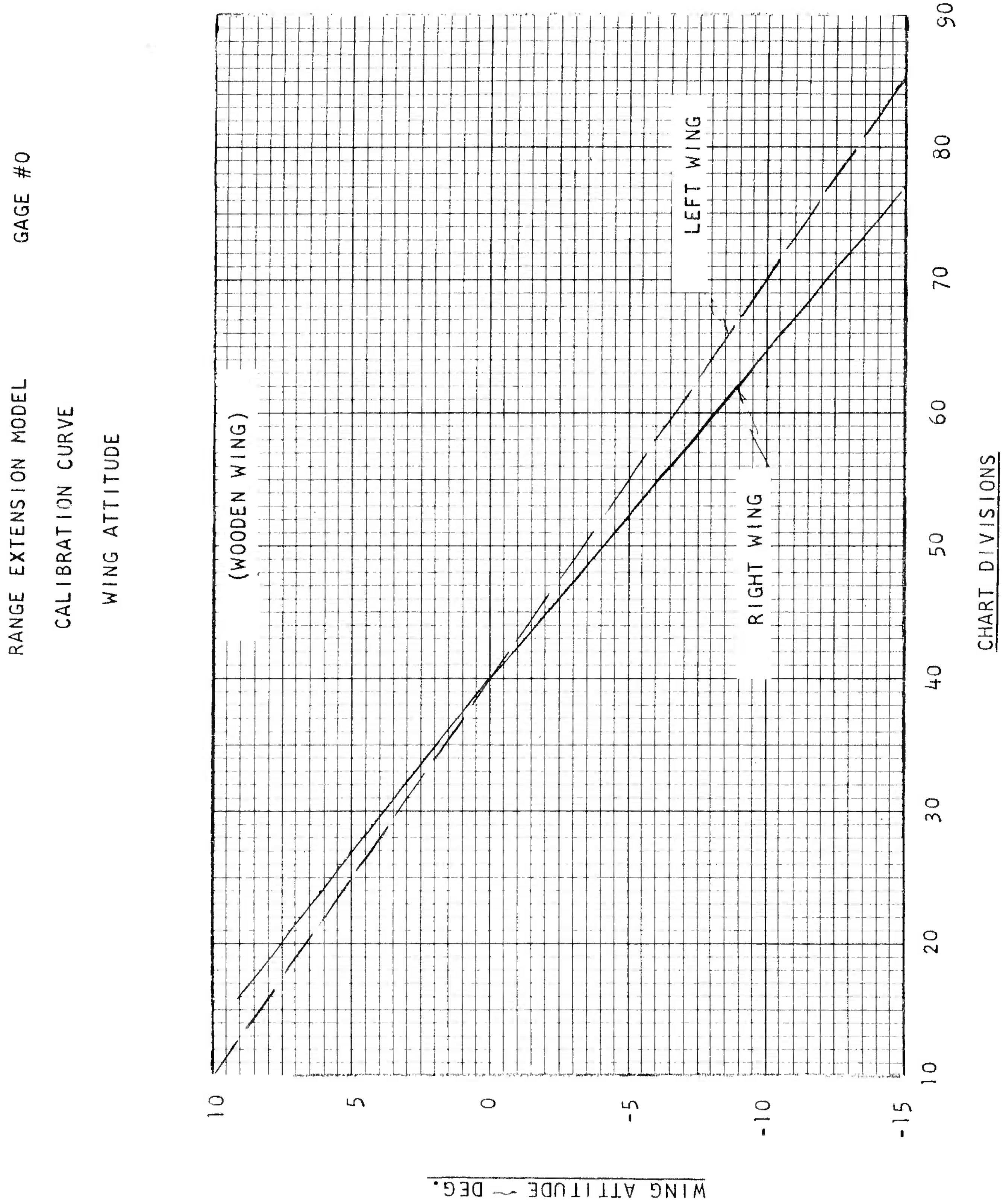

RANGE EXTENSION MODEL
CALIBRATION CURVE
WING ATTITUDE
GAGE #0
(WOODEN WING)
LEFT WING
RIGHT WING
10
20
30
40
50
60
70
80
90
CHART DIVISIONS
10
5
0
-5
-10
-15
WING ATTITUDE — DEG.

FIGURE 11

RANGE EXTENSION MODEL

CALIBRATION CURVE

FUSELAGE ATTITUDE

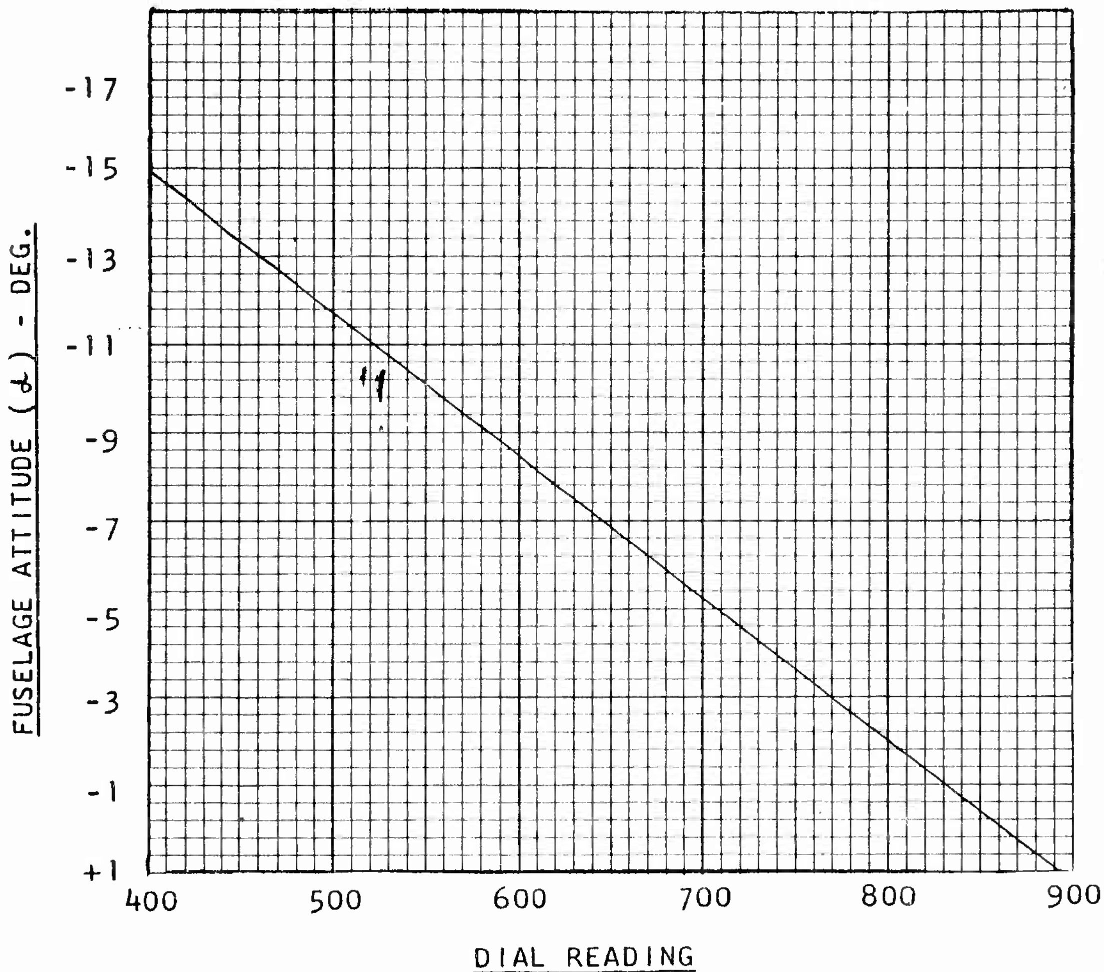


FIGURE 12

COLLECTIVE PITCH CALIBRATION CURVE

FORWARD AND REAR ROTOR

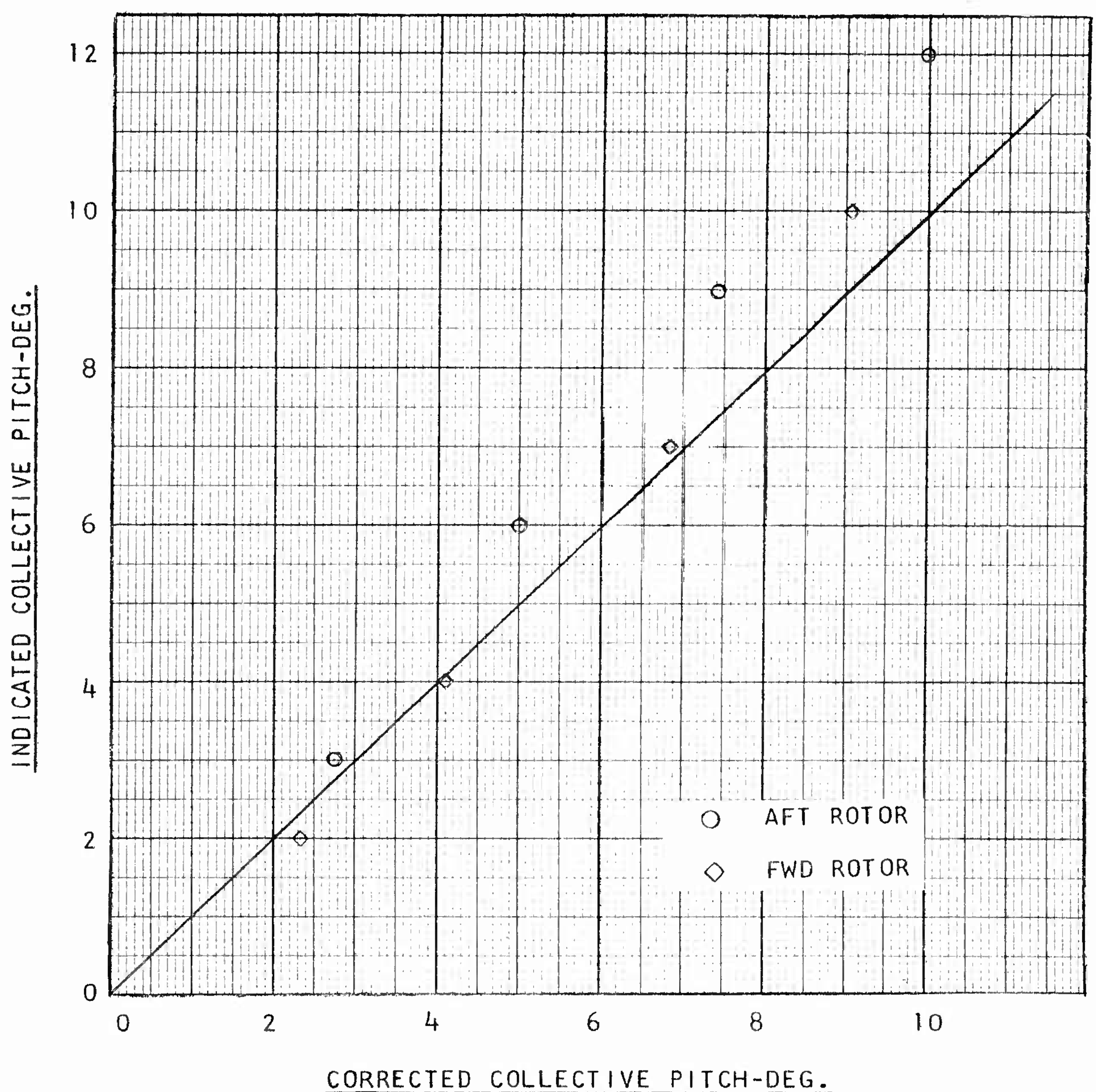


FIGURE 13

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

THRUST

ΣT VS Z

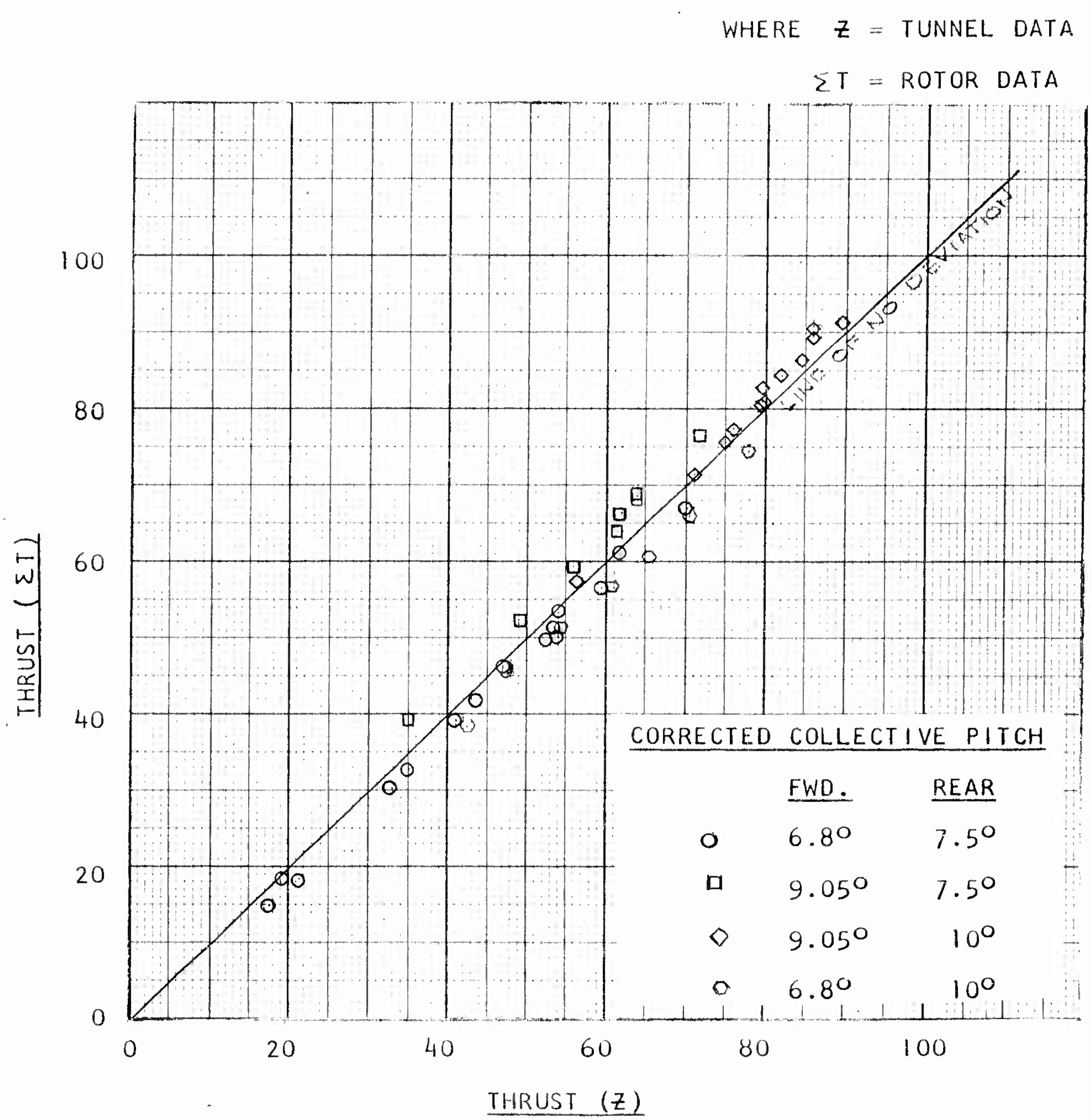


FIGURE 14

THRUST vs ANGLE OF ATTACK

FORWARD ROTOR

VELOCITY = 30 KTS.

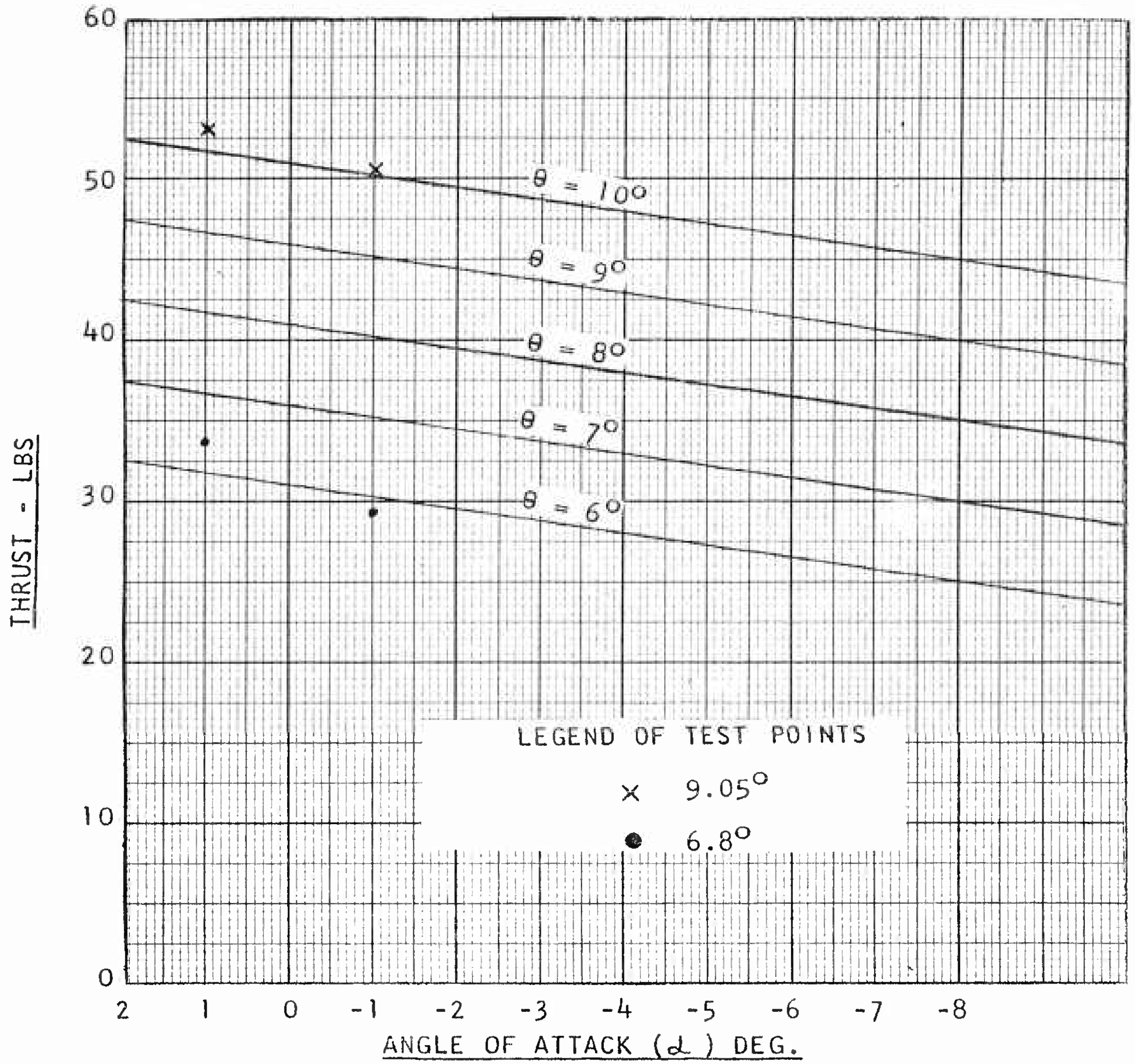


FIGURE 15

THRUST vs ANGLE OF ATTACK

FORWARD ROTOR

VELOCITY = 70 KTS.

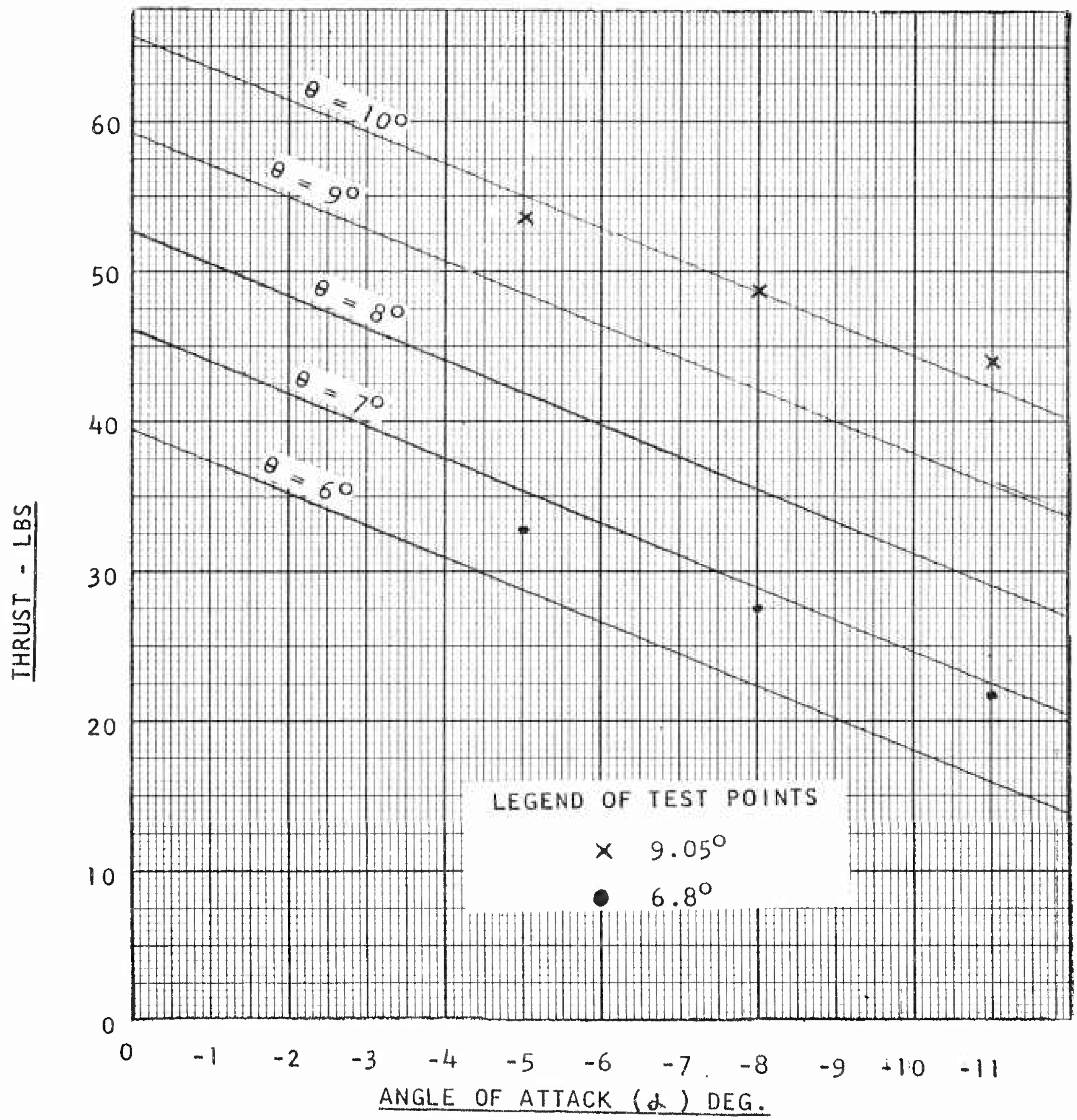


FIGURE 16

THRUST vs ANGLE OF ATTACK

FORWARD ROTOR

VELOCITY = 85 KTS.

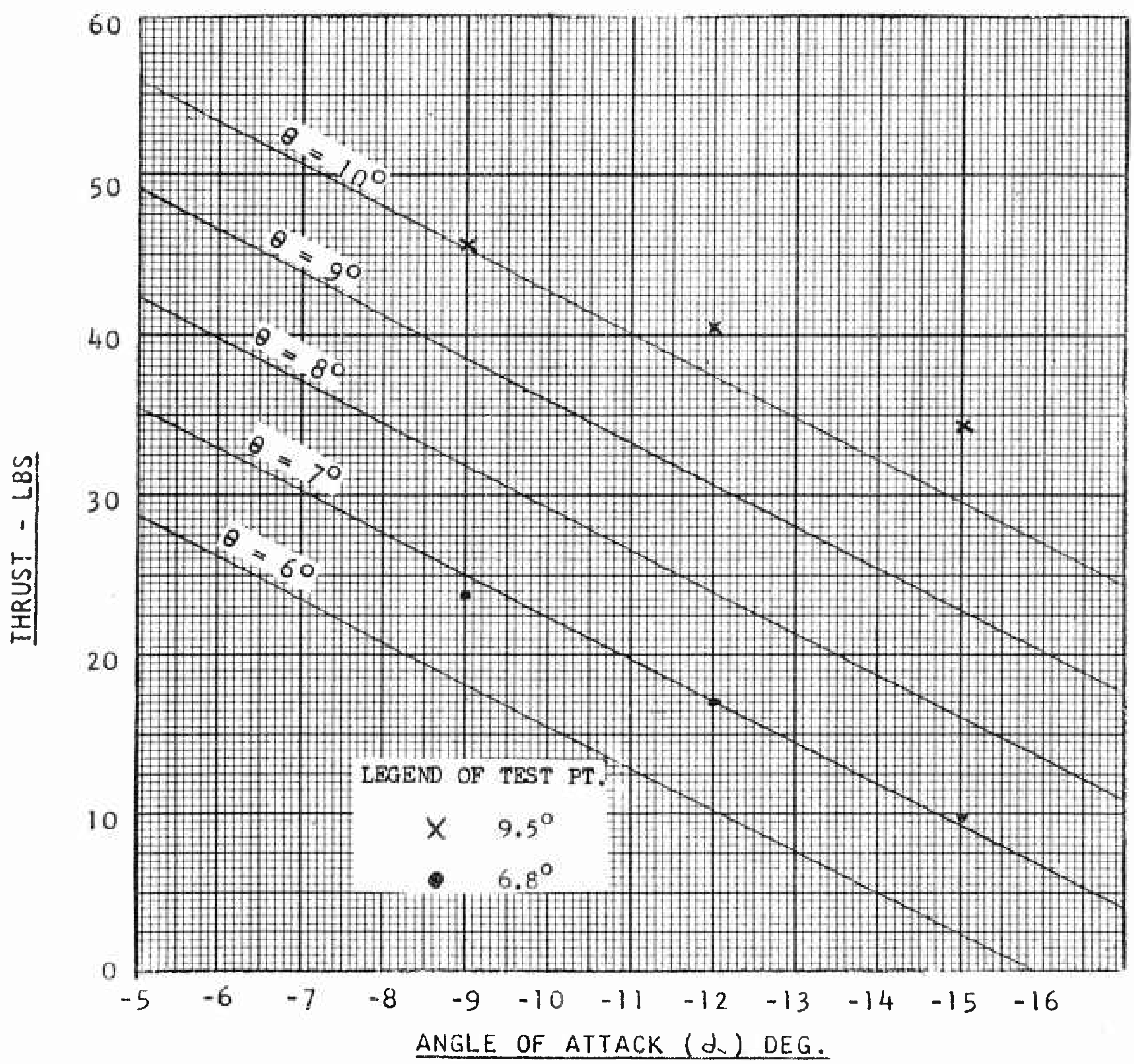


FIGURE 17

THRUST vs ANGLE OF ATTACK

REAR ROTOR

VELOCITY = 30 KTS.

FORWARD COLLECTIVE PITCH 7° (6.8°)

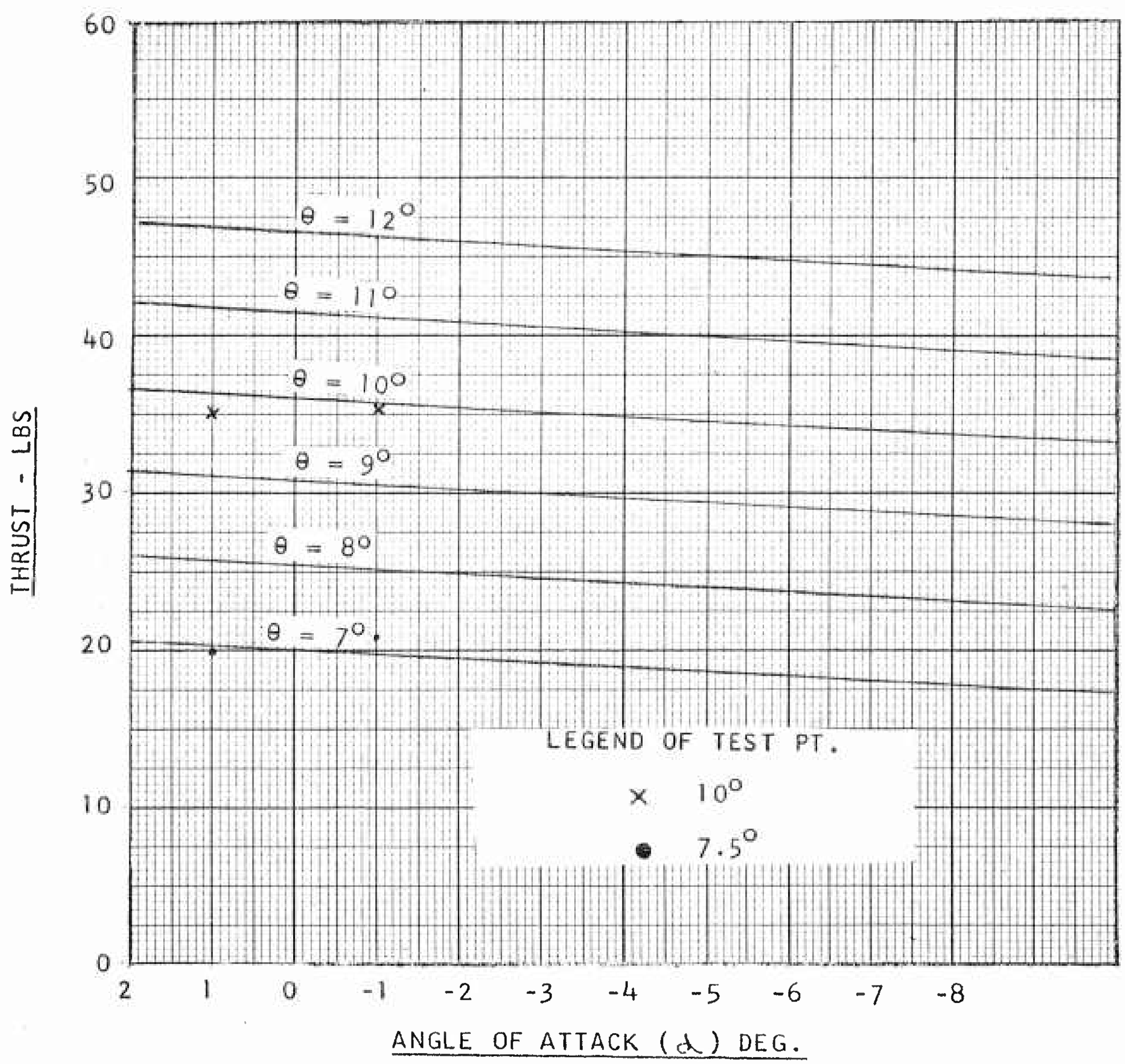


FIGURE 18

THRUST vs ANGLE OF ATTACK

REAR ROTOR

VELOCITY = 70 KTS

FORWARD COLLECTIVE PITCH 7° (6.8)

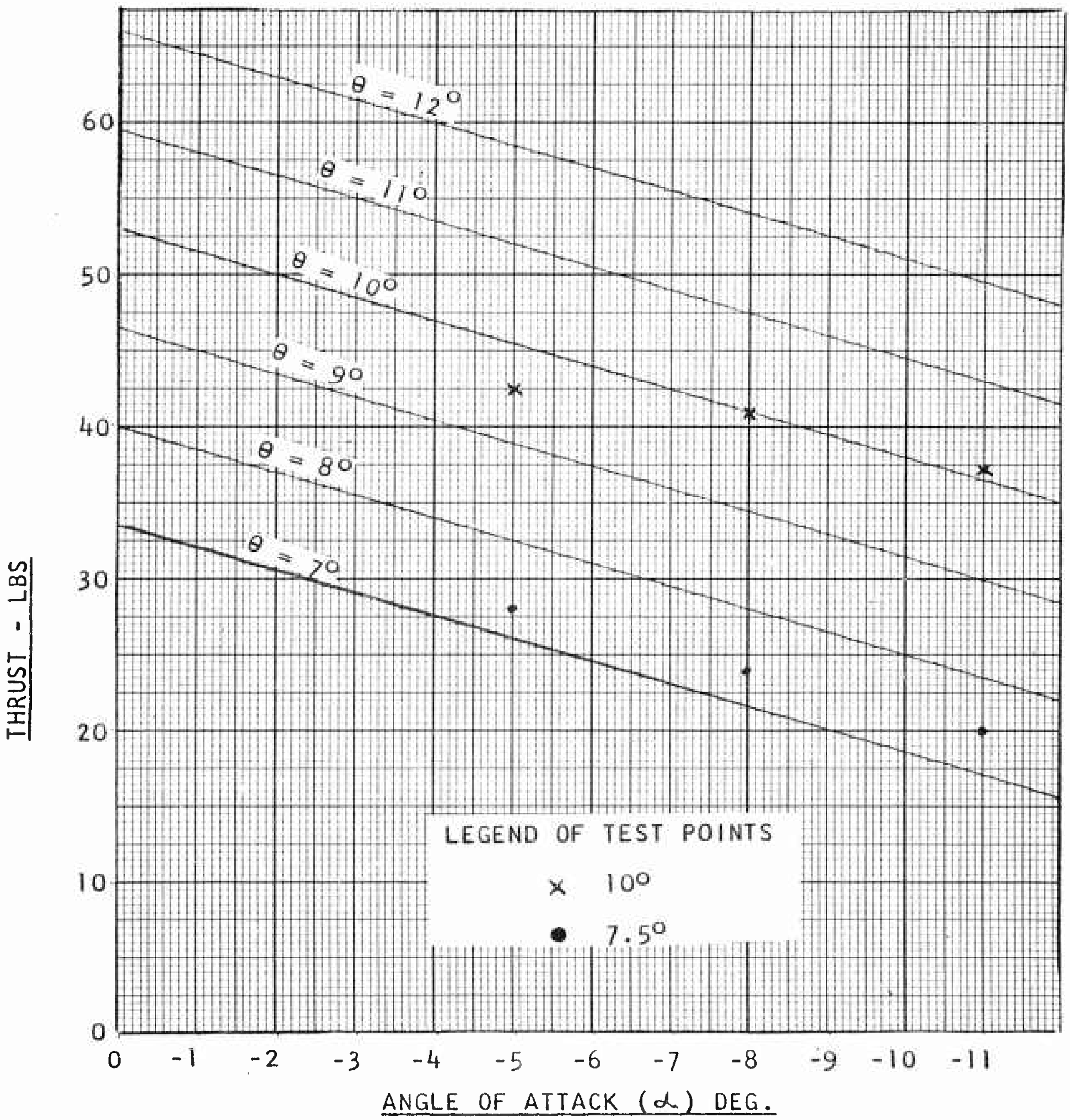


FIGURE 19

THRUST vs ANGLE OF ATTACK

REAR ROTOR

VELOCITY = 85 KTS.

FORWARD COLLECTIVE PITCH 7° (6.8°)

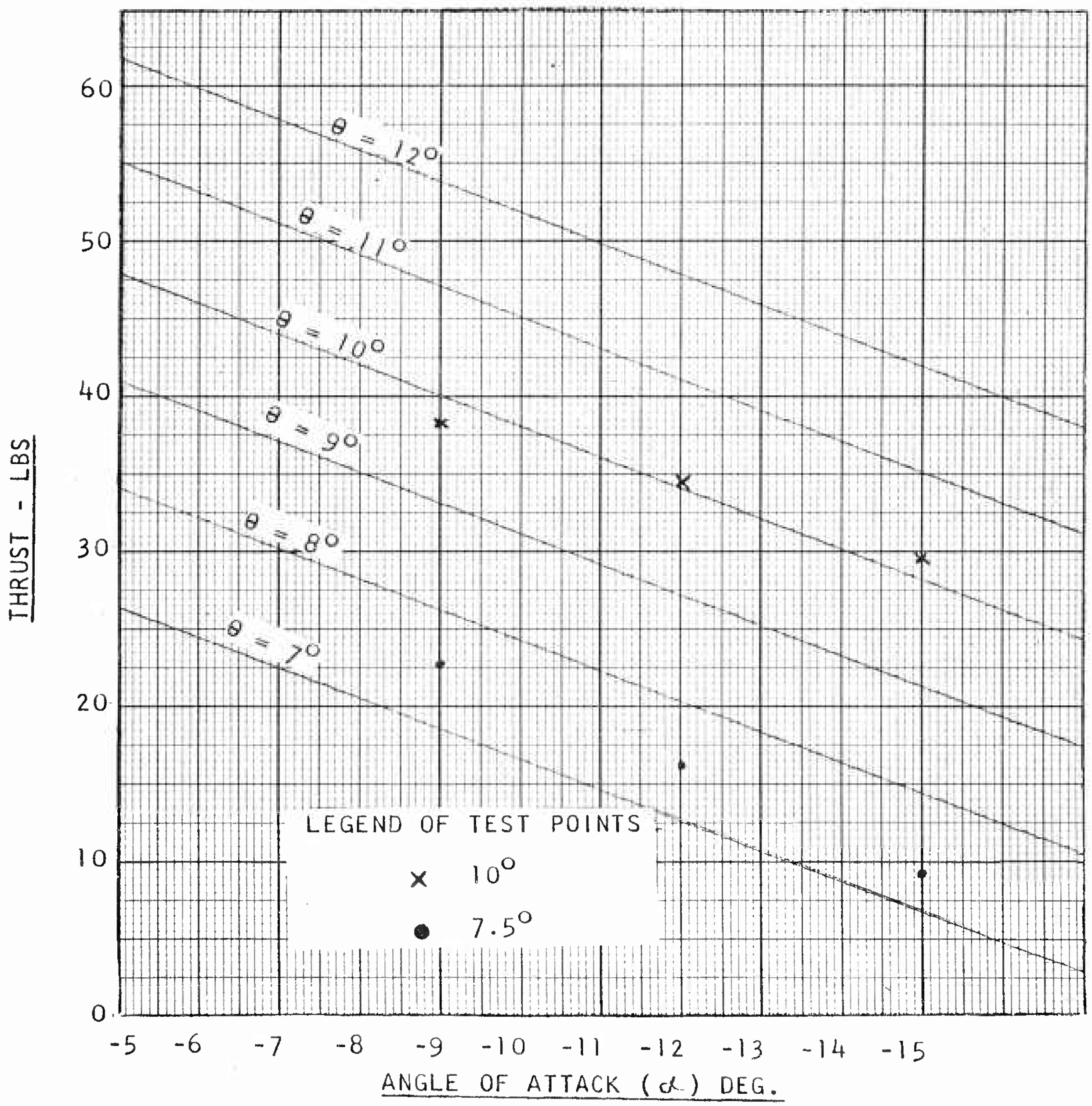


FIGURE 20

THRUST vs ANGLE OF ATTACK

REAR ROTOR

VELOCITY = 30 KTS.

FORWARD COLLECTIVE PITCH 10° (9.05°)

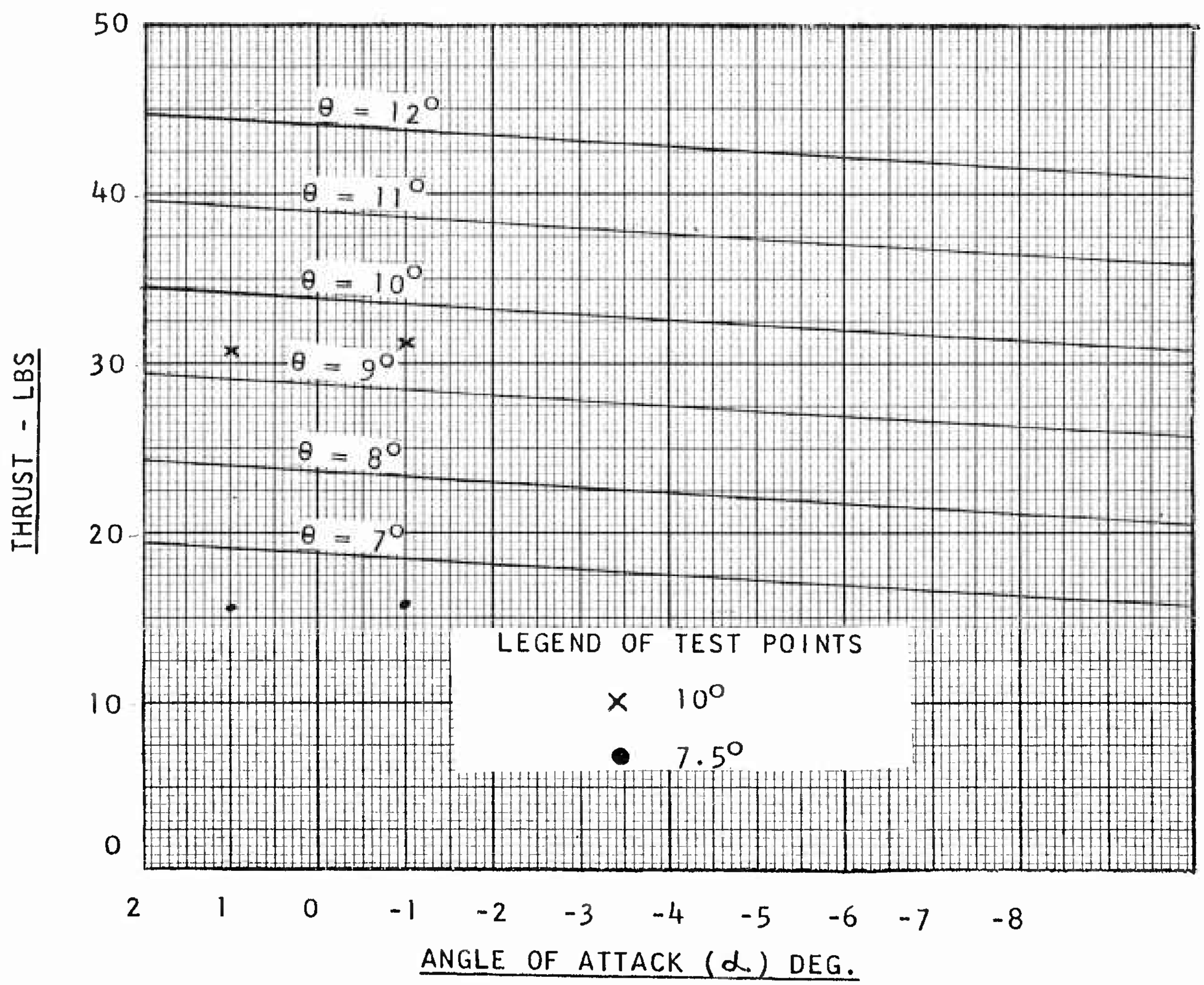


FIGURE 21

THRUST vs ANGLE OF ATTACK

REAR ROTOR

VELOCITY = 70 KTS.

FORWARD COLLECTIVE PITCH 10° (9.05°)

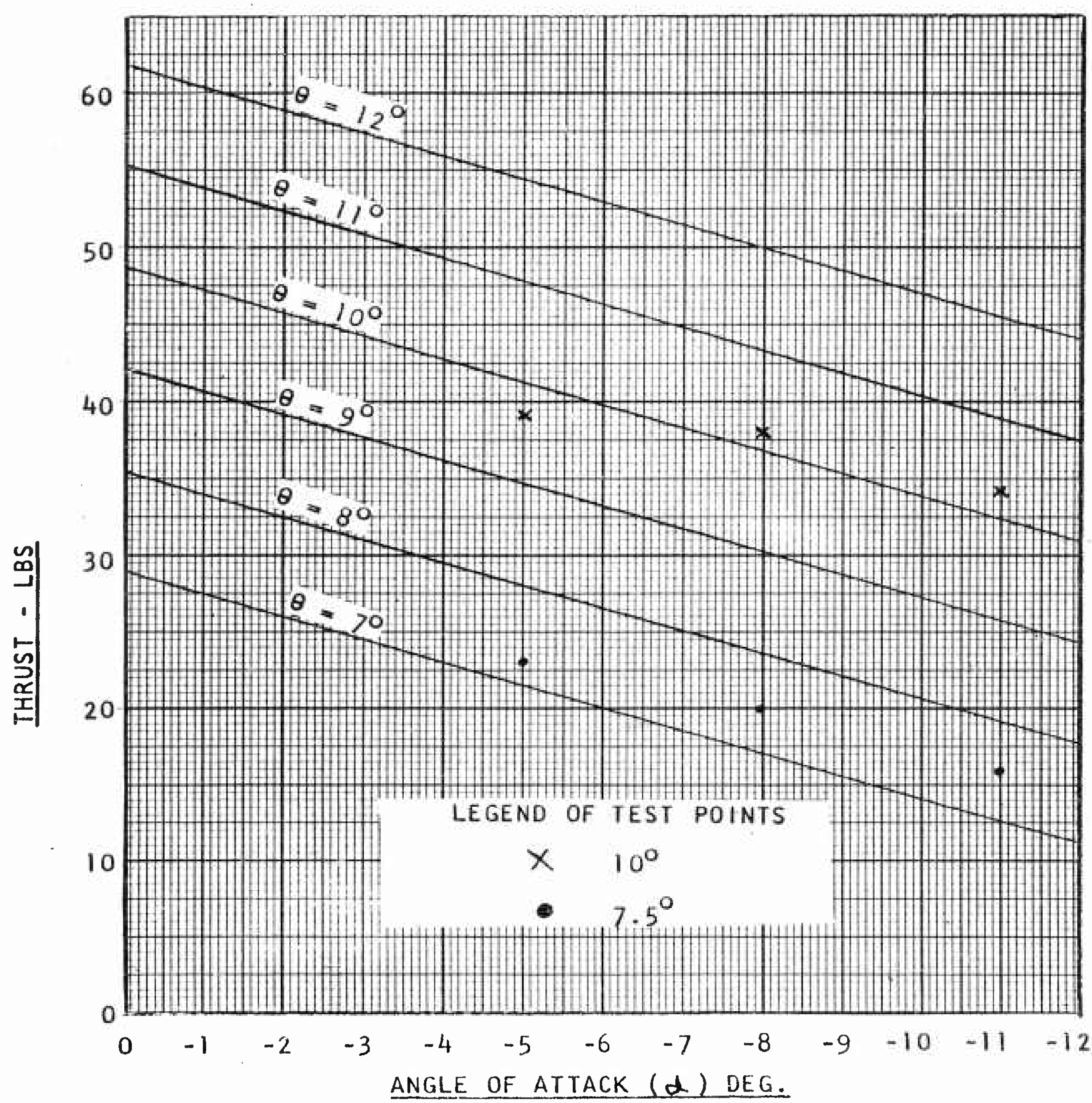


FIGURE 22

THRUST vs ANGLE OF ATTACK

REAR ROTOR

VELOCITY = 85 KTS.

FORWARD COLLECTIVE PITCH 10° (9.05)

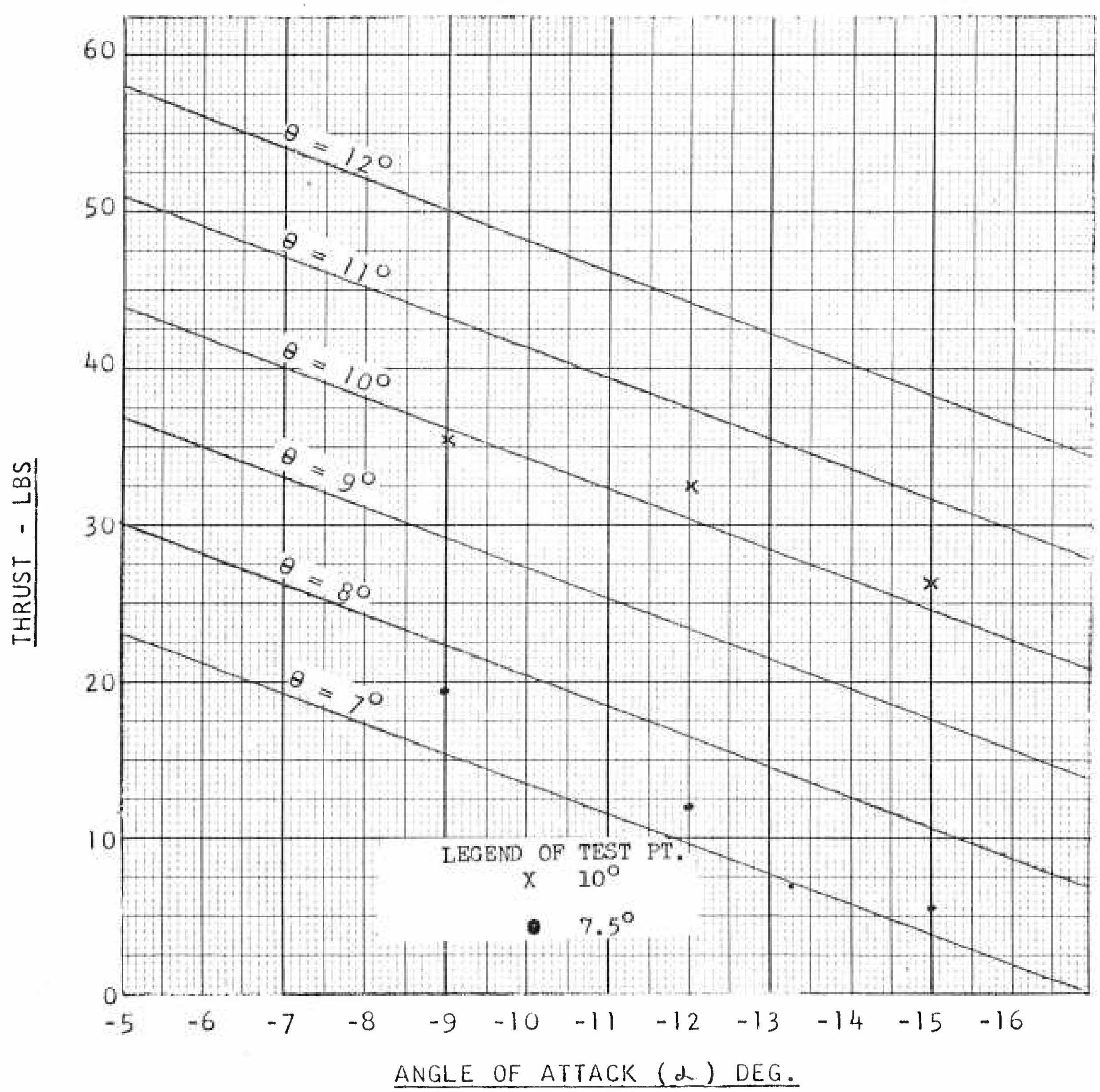


FIGURE 23

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

THRUST

MEASURED vs CALCULATED

FORWARD ROTOR

NO WING

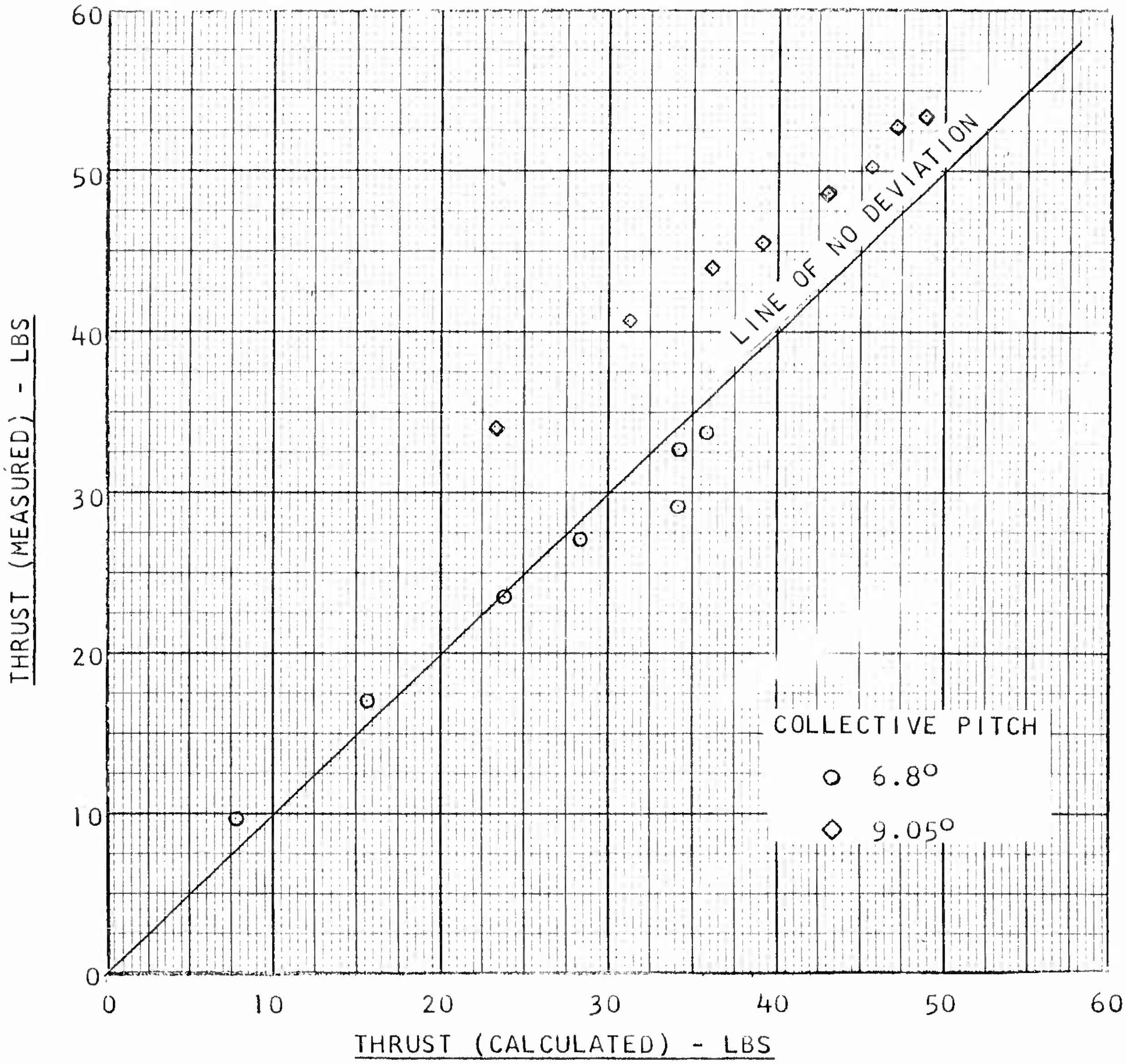


FIGURE 24

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

THRUST

MEASURED vs CALCULATED

REAR ROTOR

NO WING

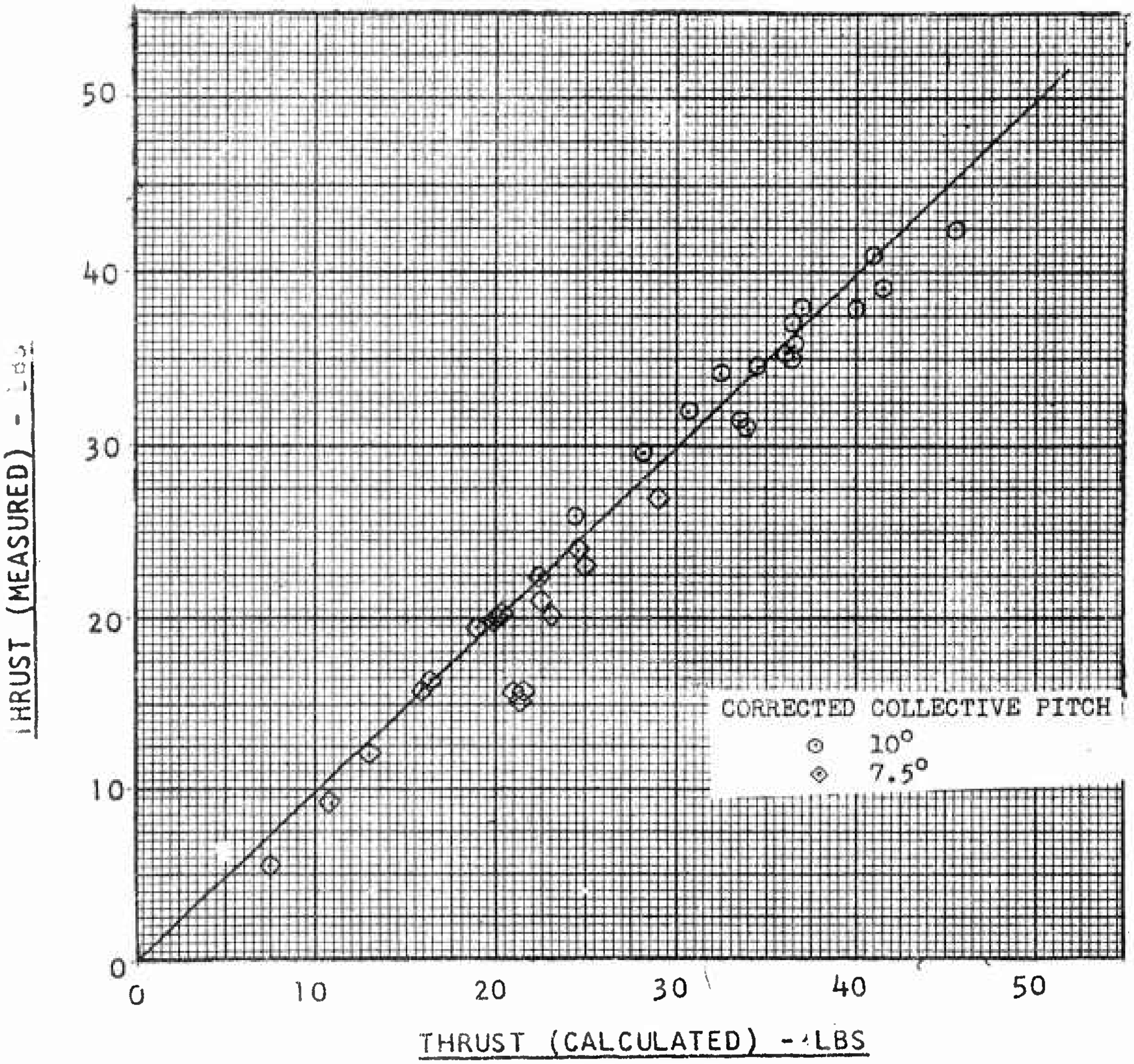


FIGURE 25

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH vs HORSEPOWER - THRUST
CONFIGURATION: NO WING
SHAFT ANGLE OF ATTACK: +1 DEG.
SPEED: 30 KTS.

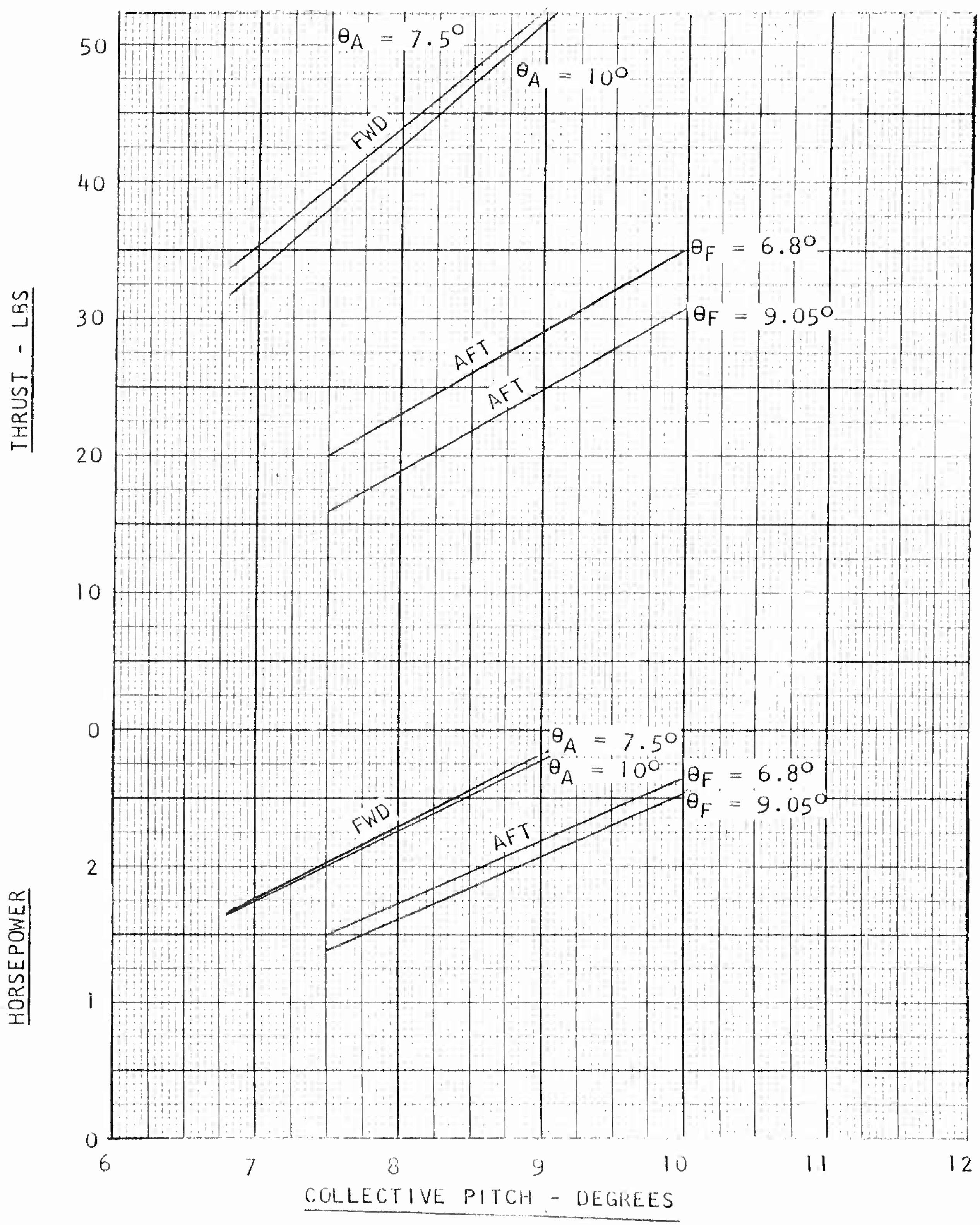


FIGURE 26

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH vs HORSEPOWER - THRUST
CONFIGURATION: WOODEN WING
SHAFT ANGLE OF ATTACK: +1 DEG.
SPEED: 30 KTS.

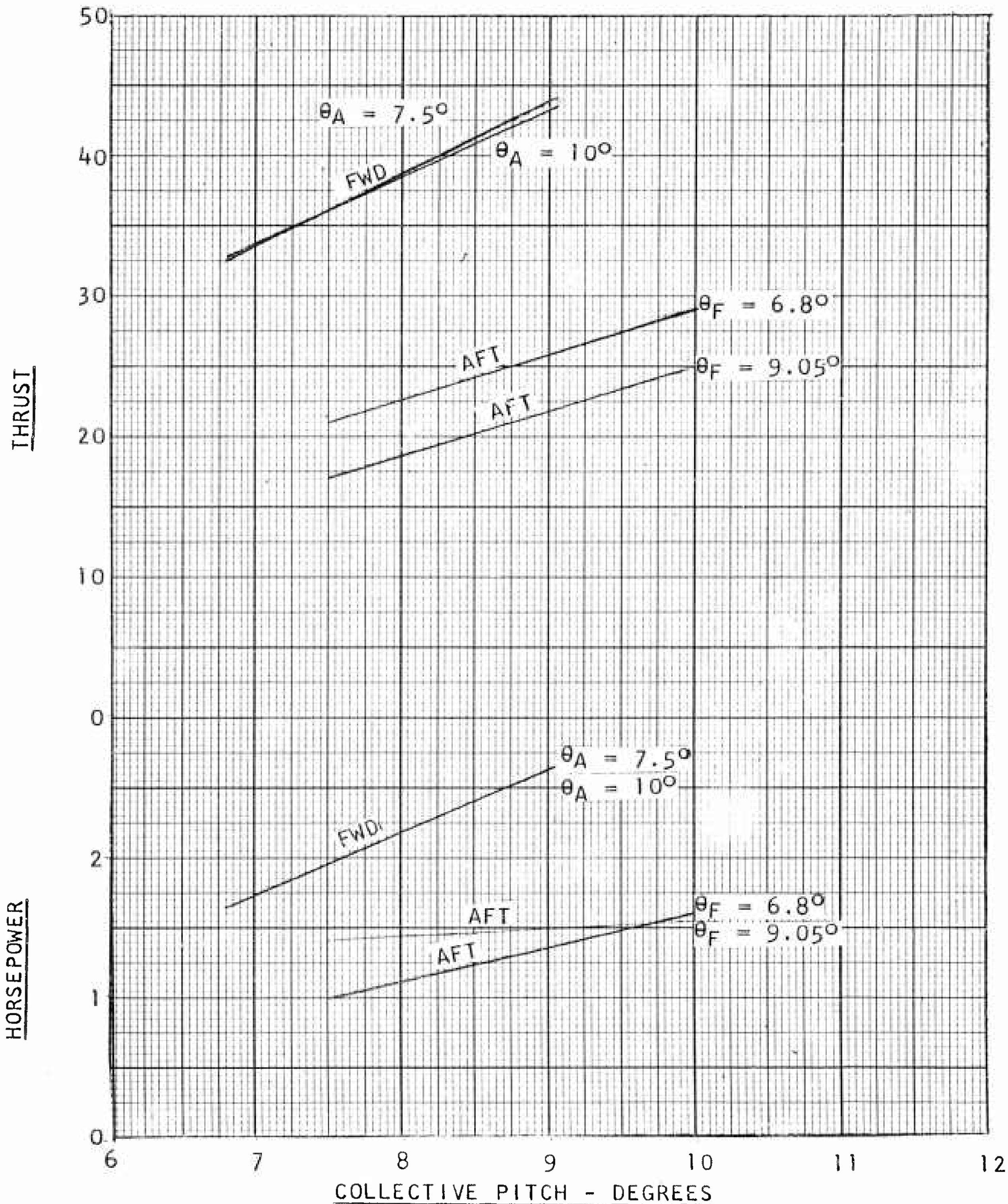


FIGURE 27

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH VS. HORSEPOWER - THRUST
CONFIGURATION: NOWING
SHAFT ANGLE OF ATTACK -1 DEG.
SPEED: 30 KTS.

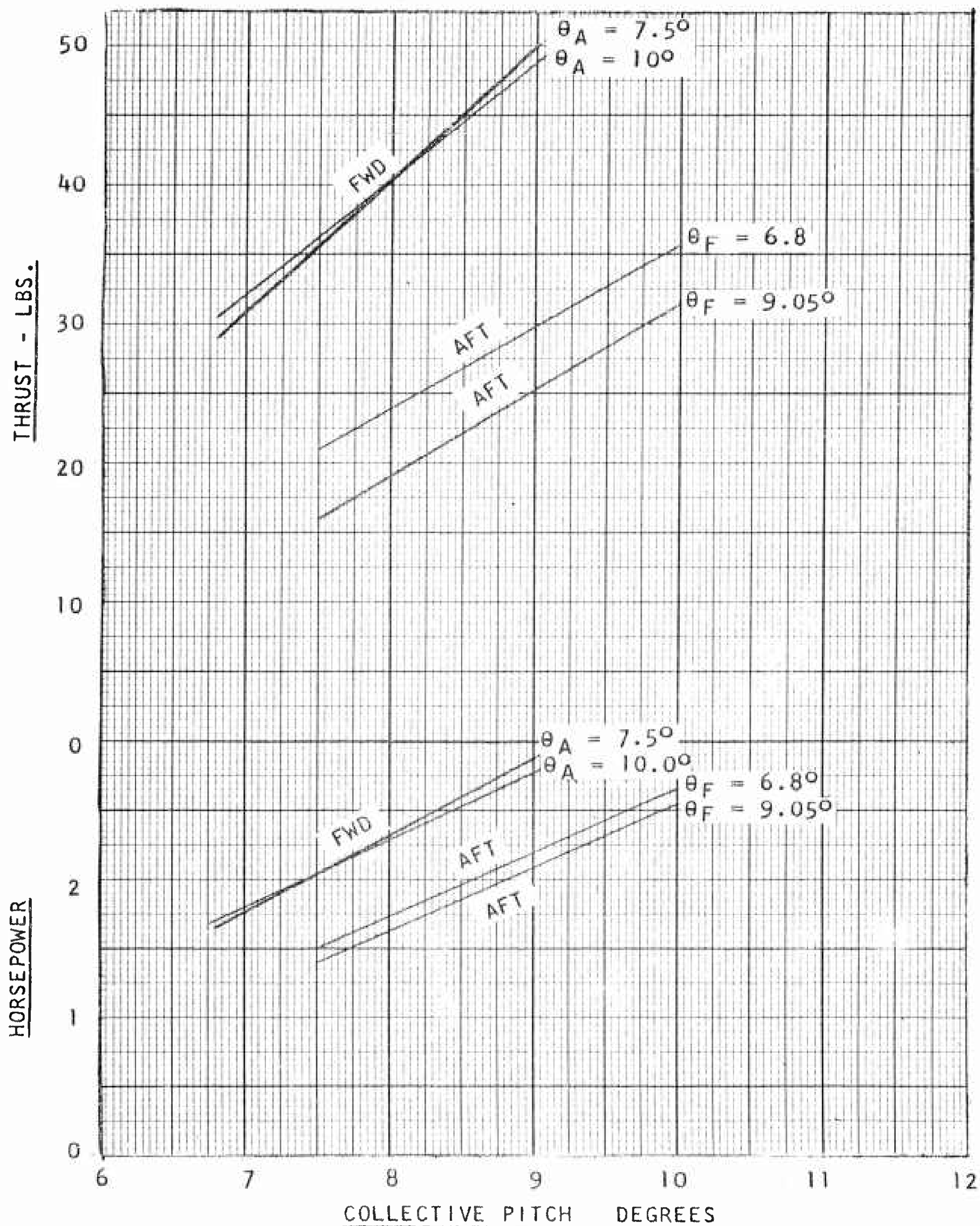


FIGURE 28

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH vs HORSEPOWER - THRUST
CONFIGURATION: WOODEN WING
SHAFT ANGLE OF ATTACK -1 DEG.
SPEED: 30 KTS.

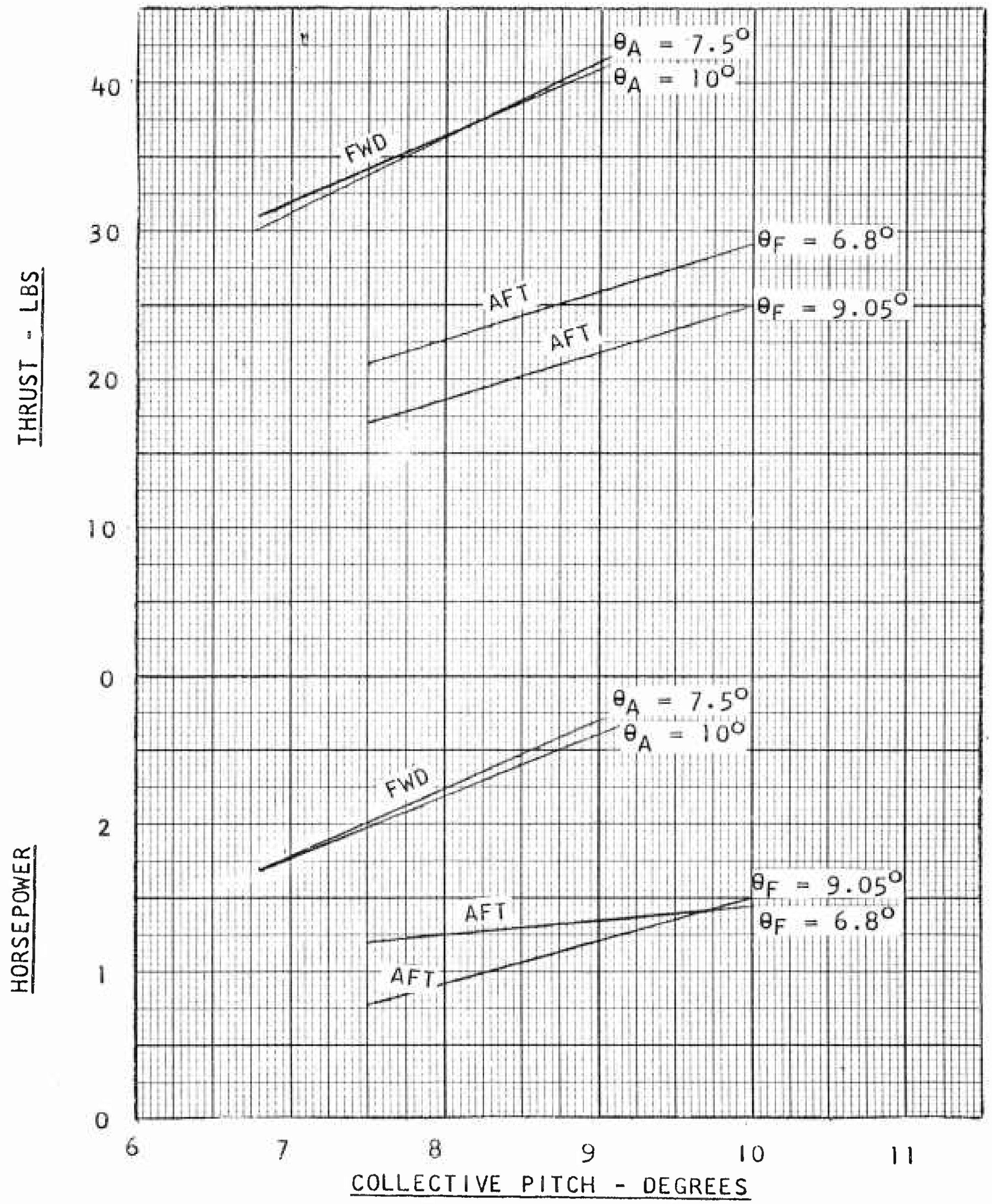


FIGURE 29

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH vs HORSEPOWER - THRUST
CONFIGURATION: NO WING
SHAFT ANGLE OF ATTACK -5 DEG.
SPEED: 70 KTS.

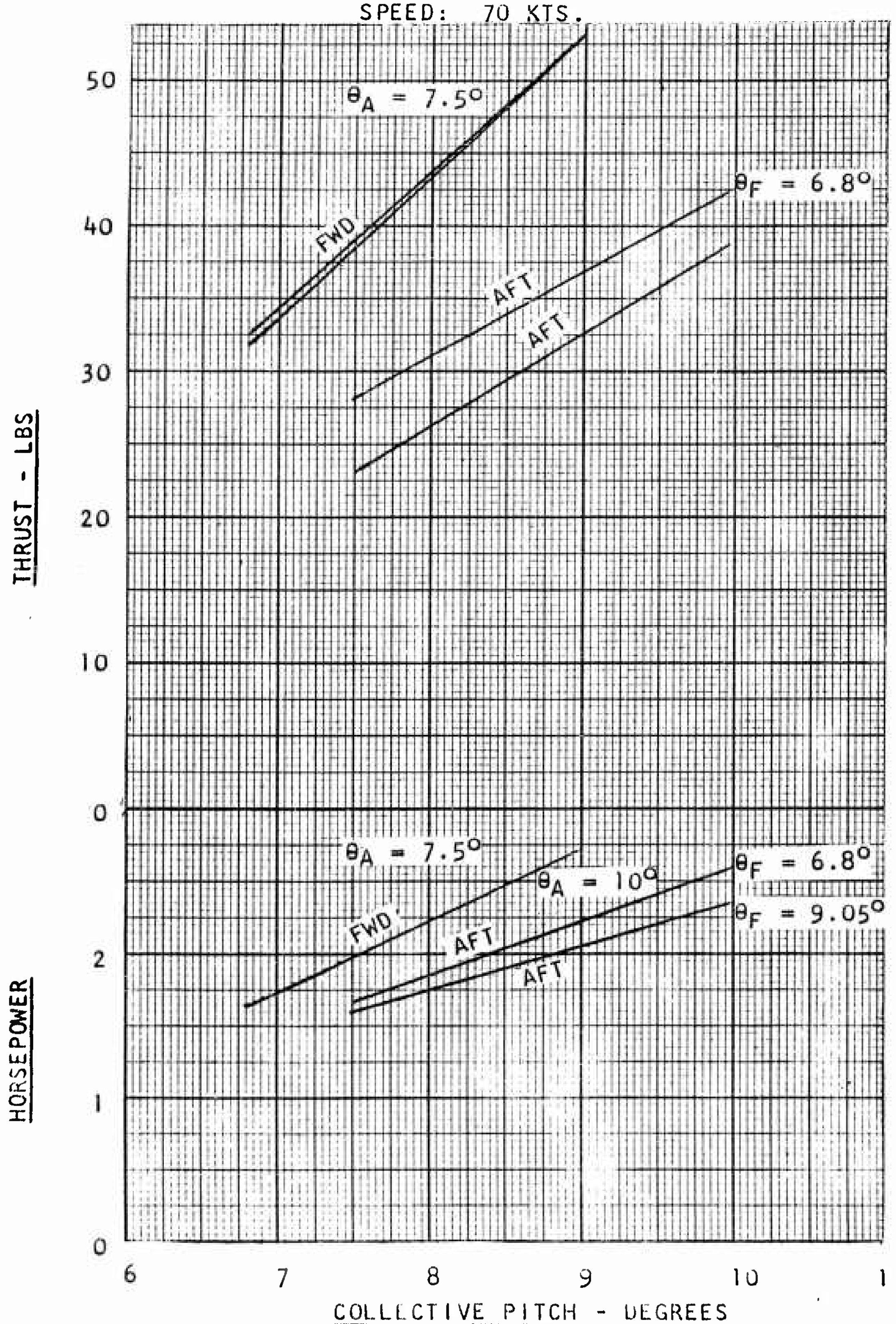


FIGURE 30

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH vs HORSEPOWER - THRUST
CONFIGURATION: WOODEN WING
SHAFT ANGLE OF ATTACK -5 DEG.
SPEED: 70 KTS.

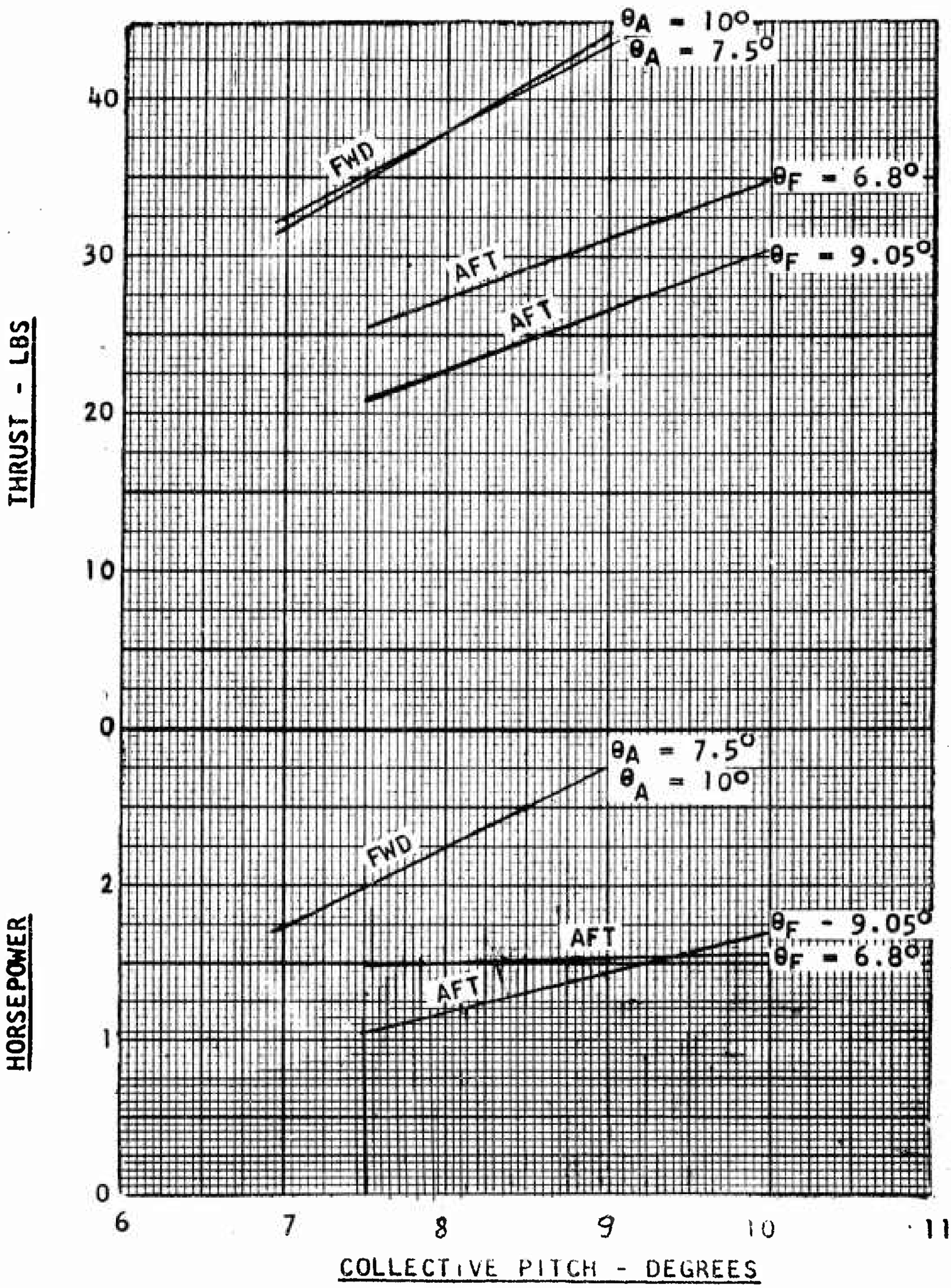


FIGURE 31

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH vs HORSEPOWER - THRUST
CONFIGURATION: NO WING
SHAFT ANGLE OF ATTACK -8 DEG.
SPEED: 70 KTS.

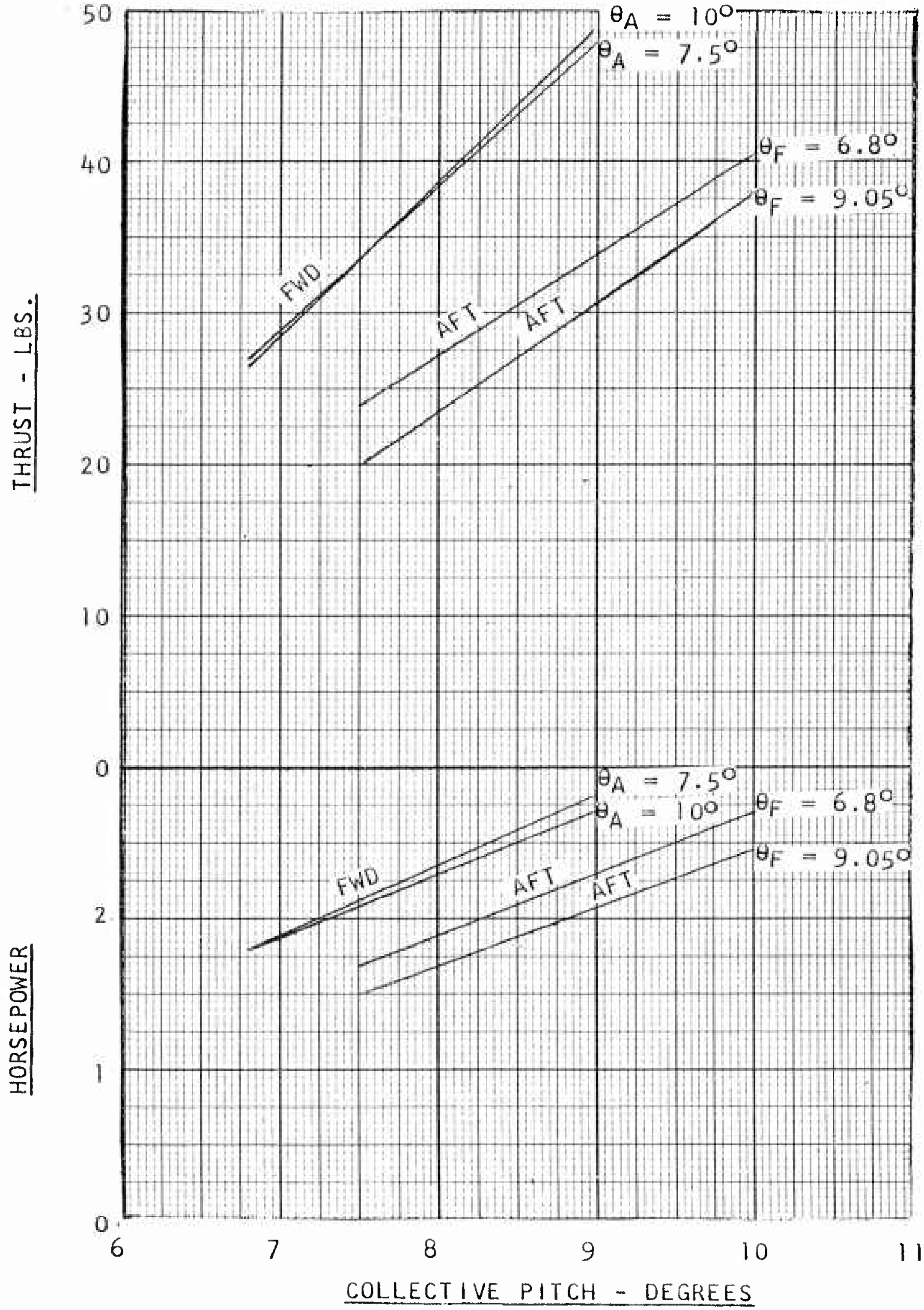


FIGURE 32

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH vs HORSEPOWER - THRUST
CONFIGURATION: WOODEN WING
SHAFT ANGLE OF ATTACK -8 DEG.
SPEED: 70 KTS.

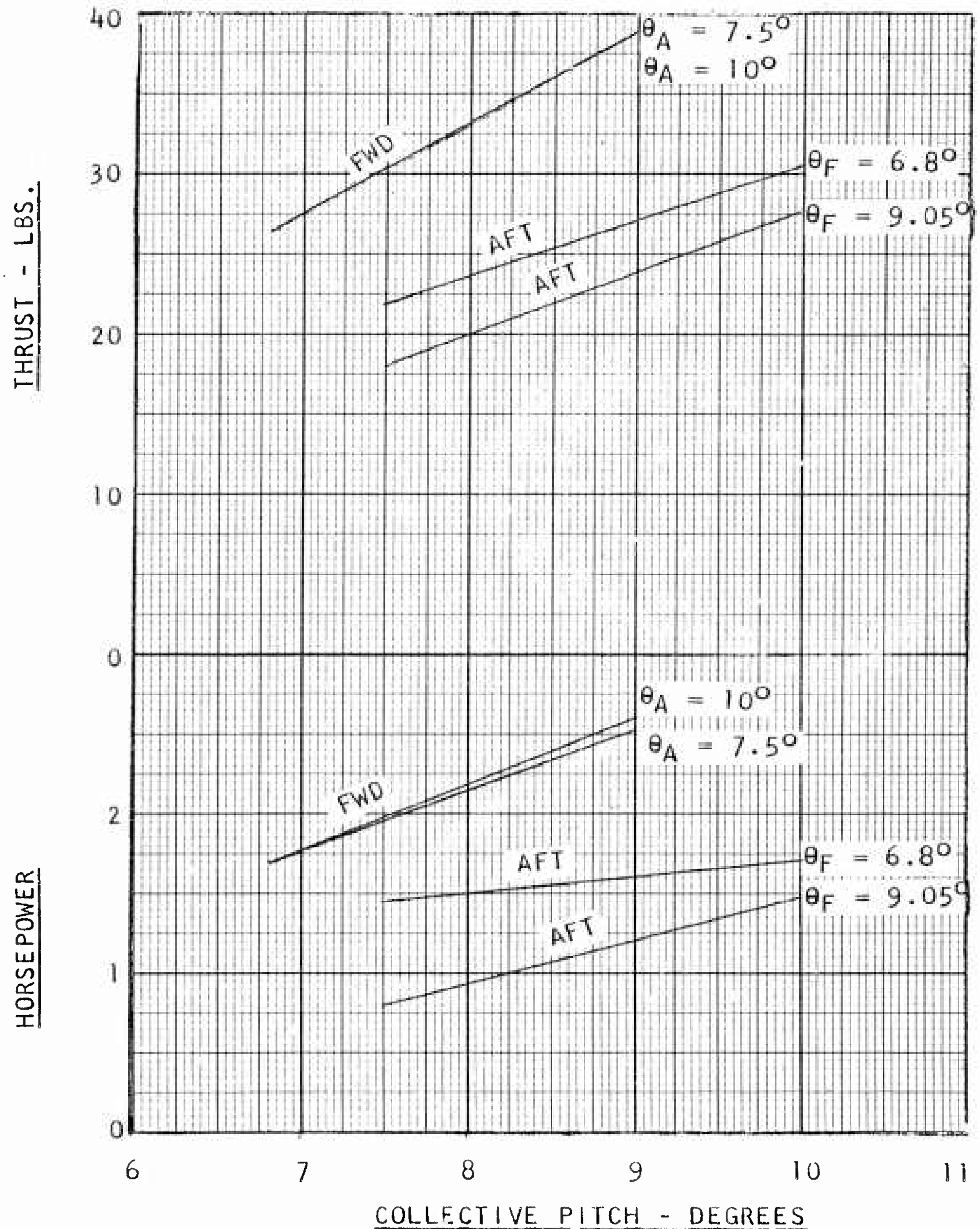


FIGURE 33

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH vs HORSEPOWER - THRUST
CONFIGURATION: NO WING
SHAFT ANGLE OF ATTACK -11 DEG.
SPEED: 70 KTS.

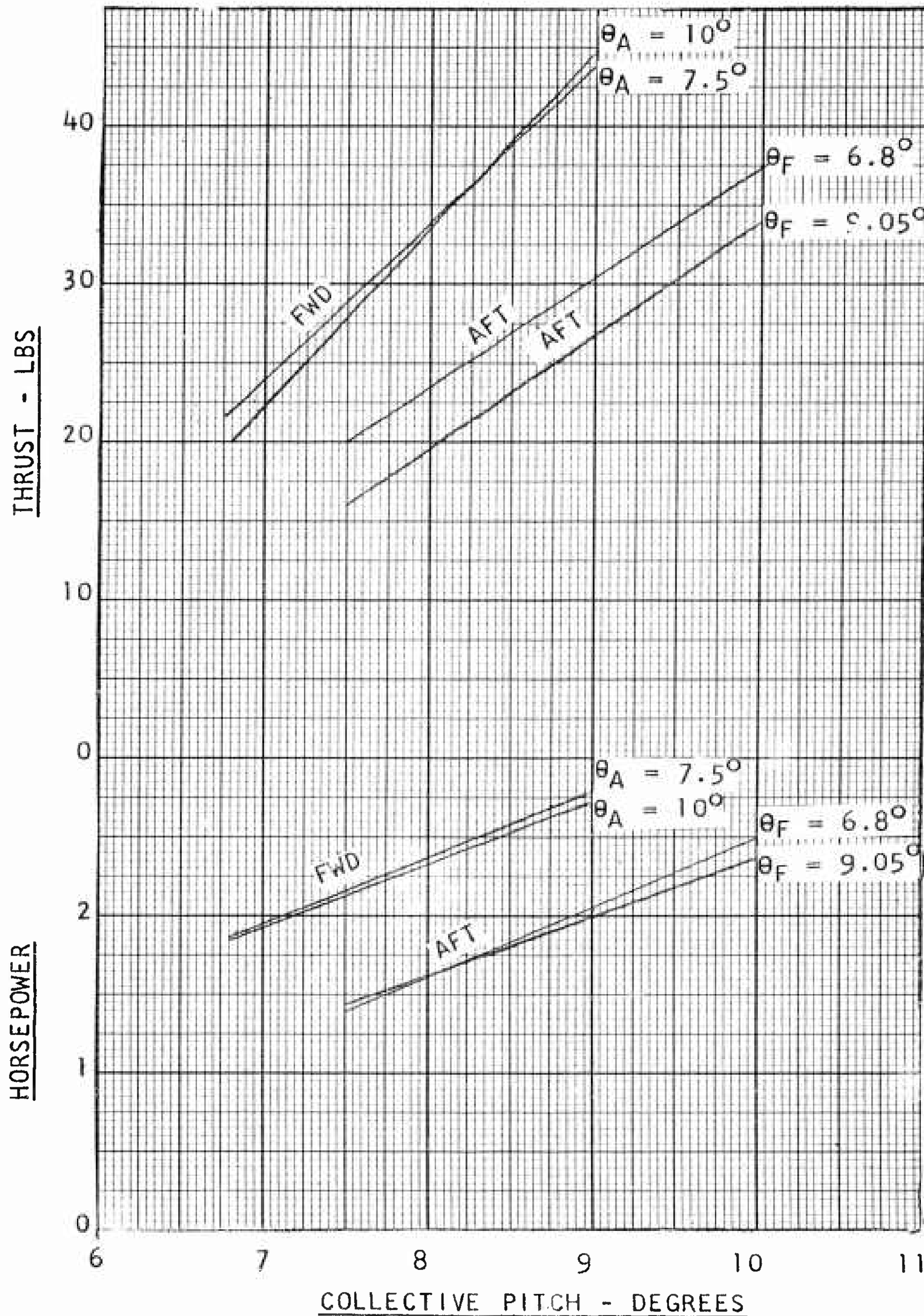


FIGURE 34

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH vs HORSEPOWER - THRUST
CONFIGURATION: WOODEN WING
SHAFT ANGLE OF ATTACK -11 DEG.
SPEED: 70 KTS.

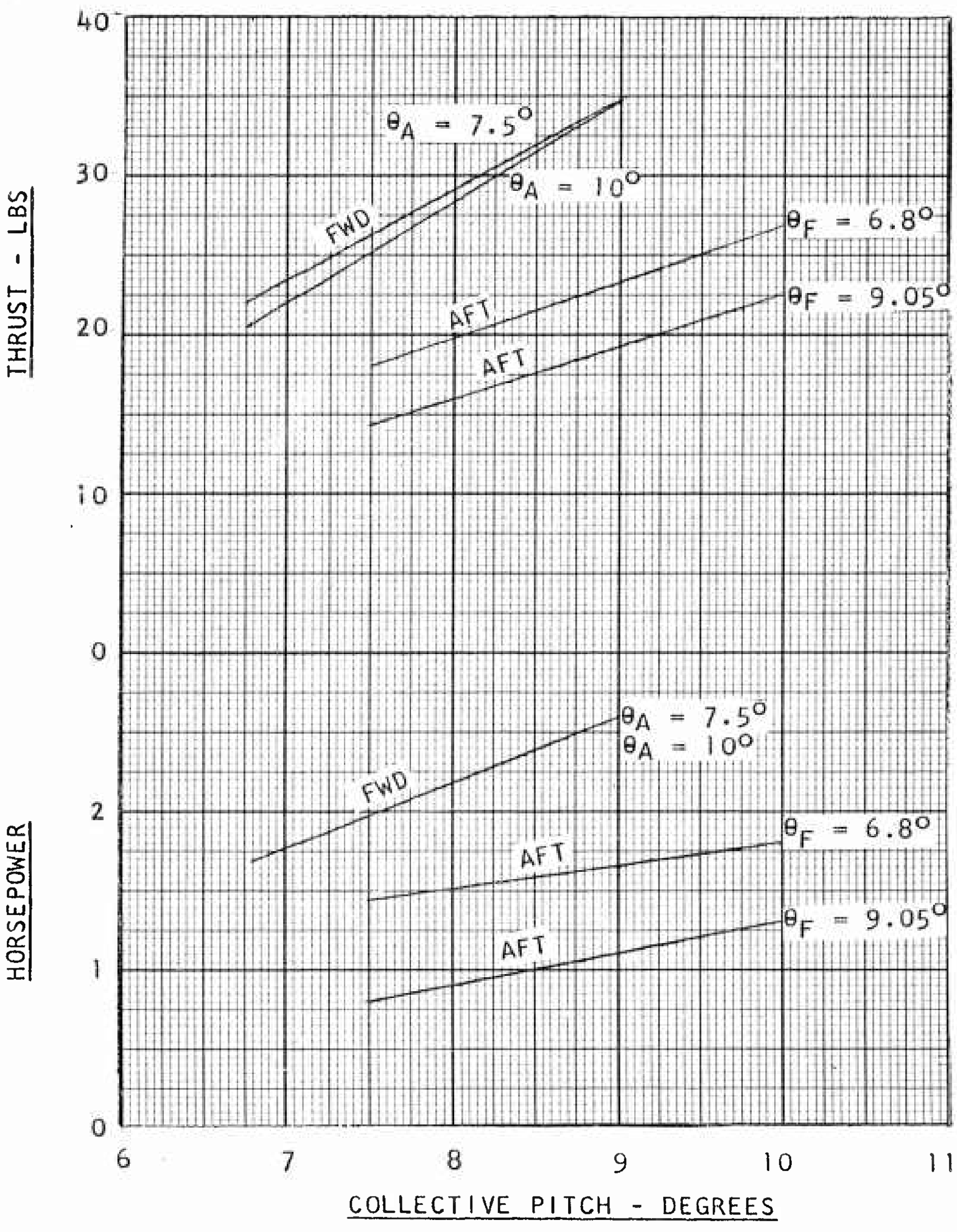


FIGURE 35

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH vs HORSEPOWER - THRUST
CONFIGURATION: NO WING
SHAFT ANGLE OF ATTACK -9 DEG.
SPEED: 85 KTS.

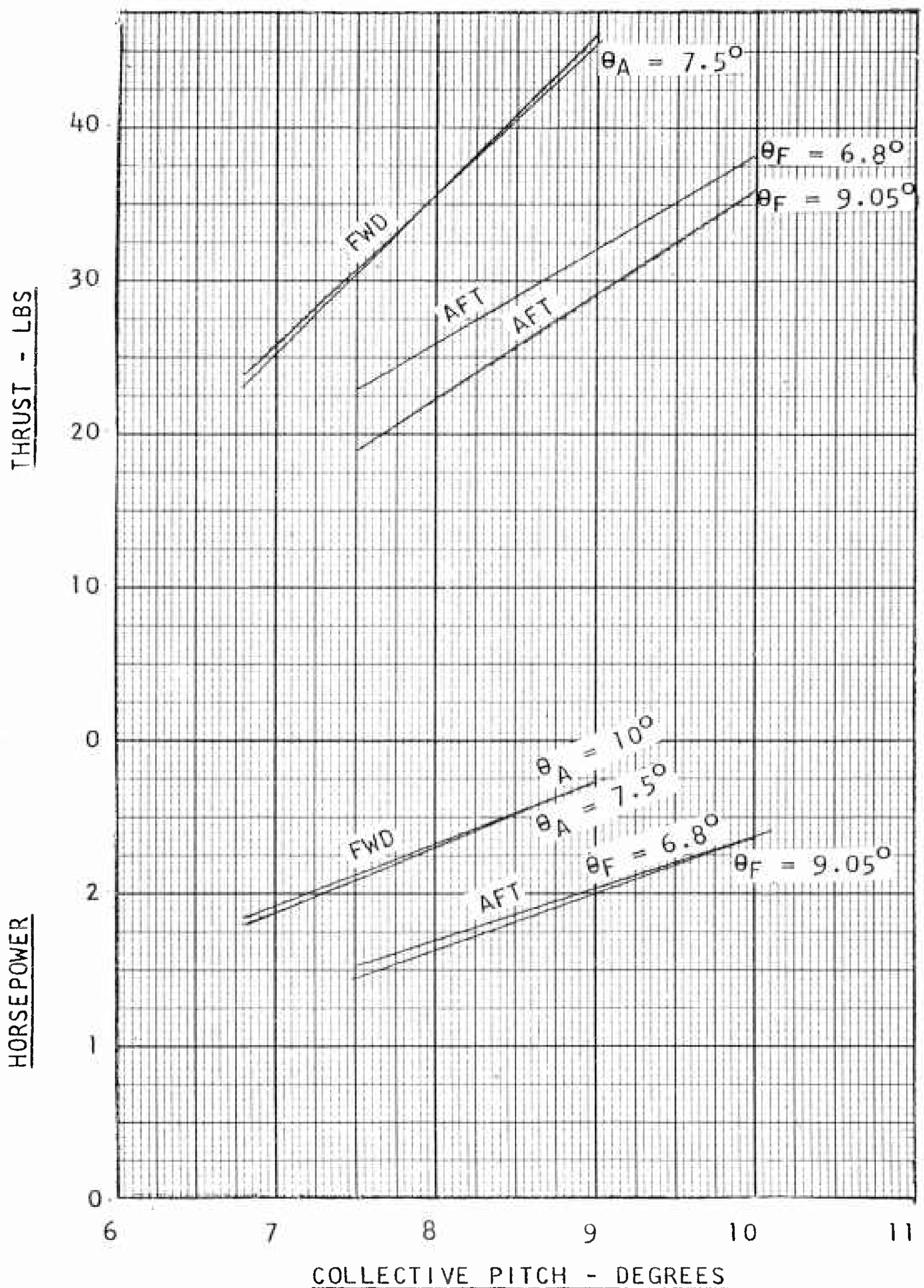


FIGURE 36

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH vs HORSEPOWER - THRUST
CONFIGURATION: WOODEN WING
SHAFT ANGLE OF ATTACK -9 DEG.
SPEED: 85 KTS.

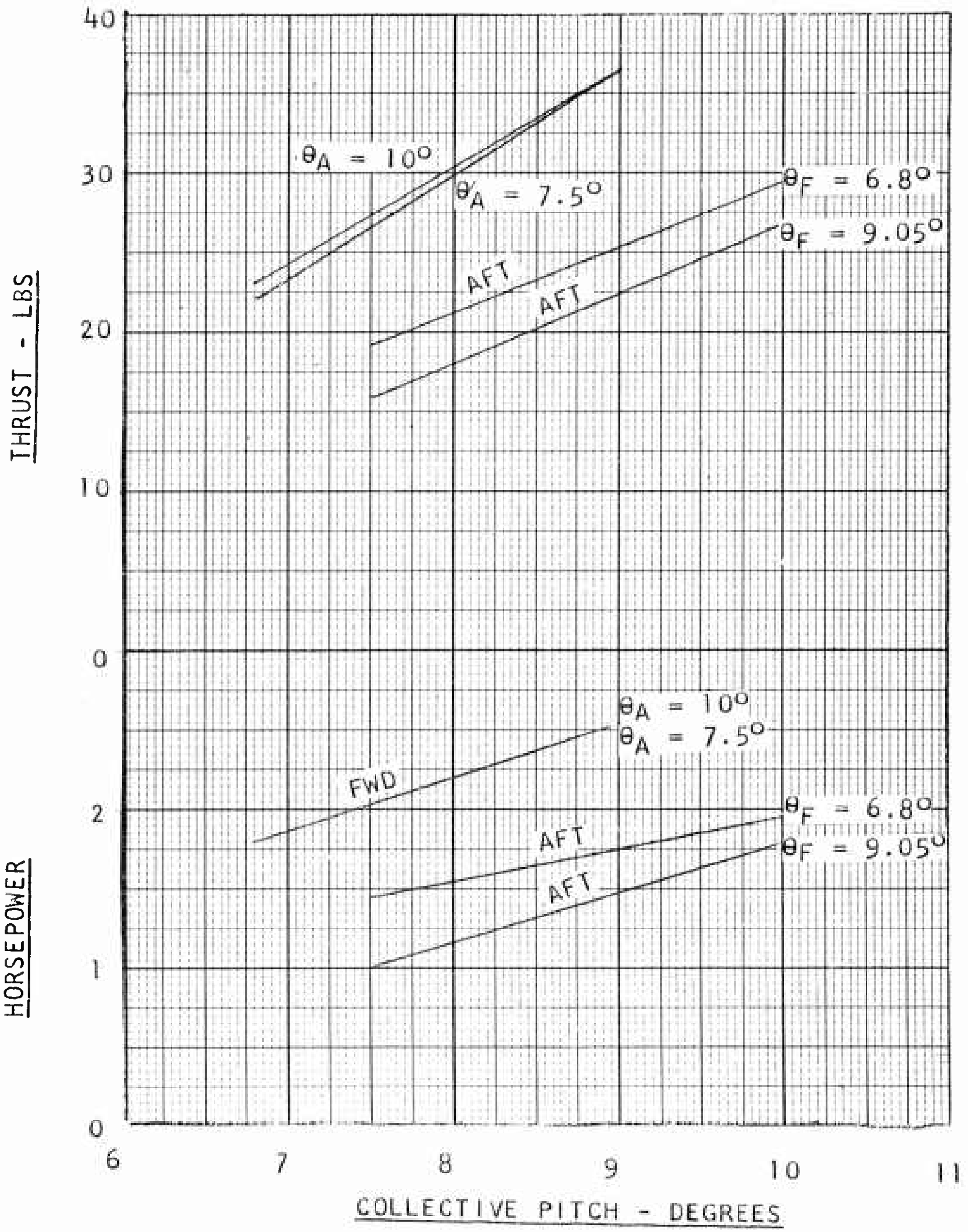


FIGURE 37

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH vs HORSEPOWER - THRUST
CONFIGURATION: METAL WING
SHAFT ANGLE OF ATTACK -9 DEG.
SPEED: 85 KTS.

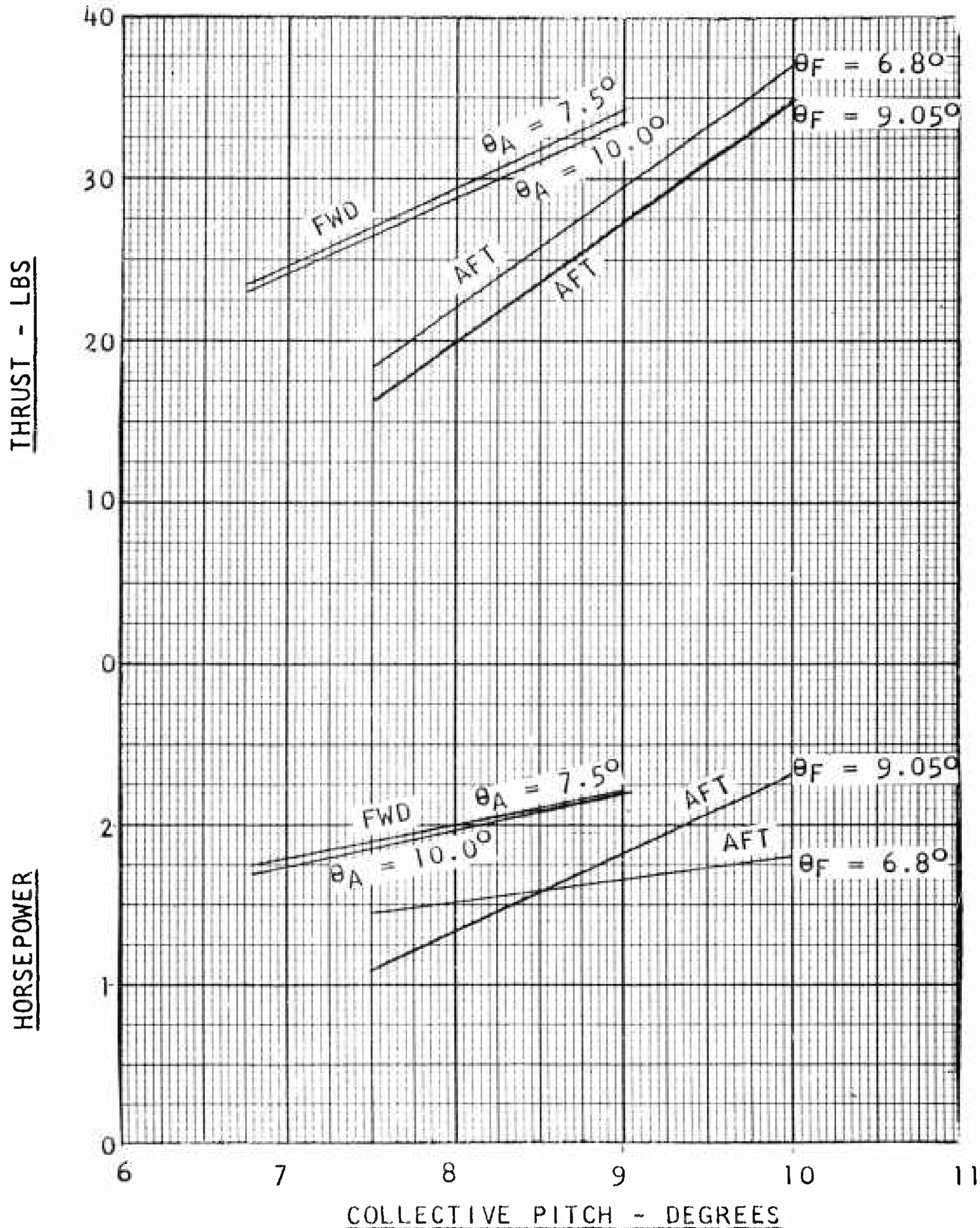


FIGURE 38

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH vs HORSEPOWER - THRUST
CONFIGURATION: NO WING
SHAFT ANGLE OF ATTACK -12 DEG.
SPEED: 85 KTS.

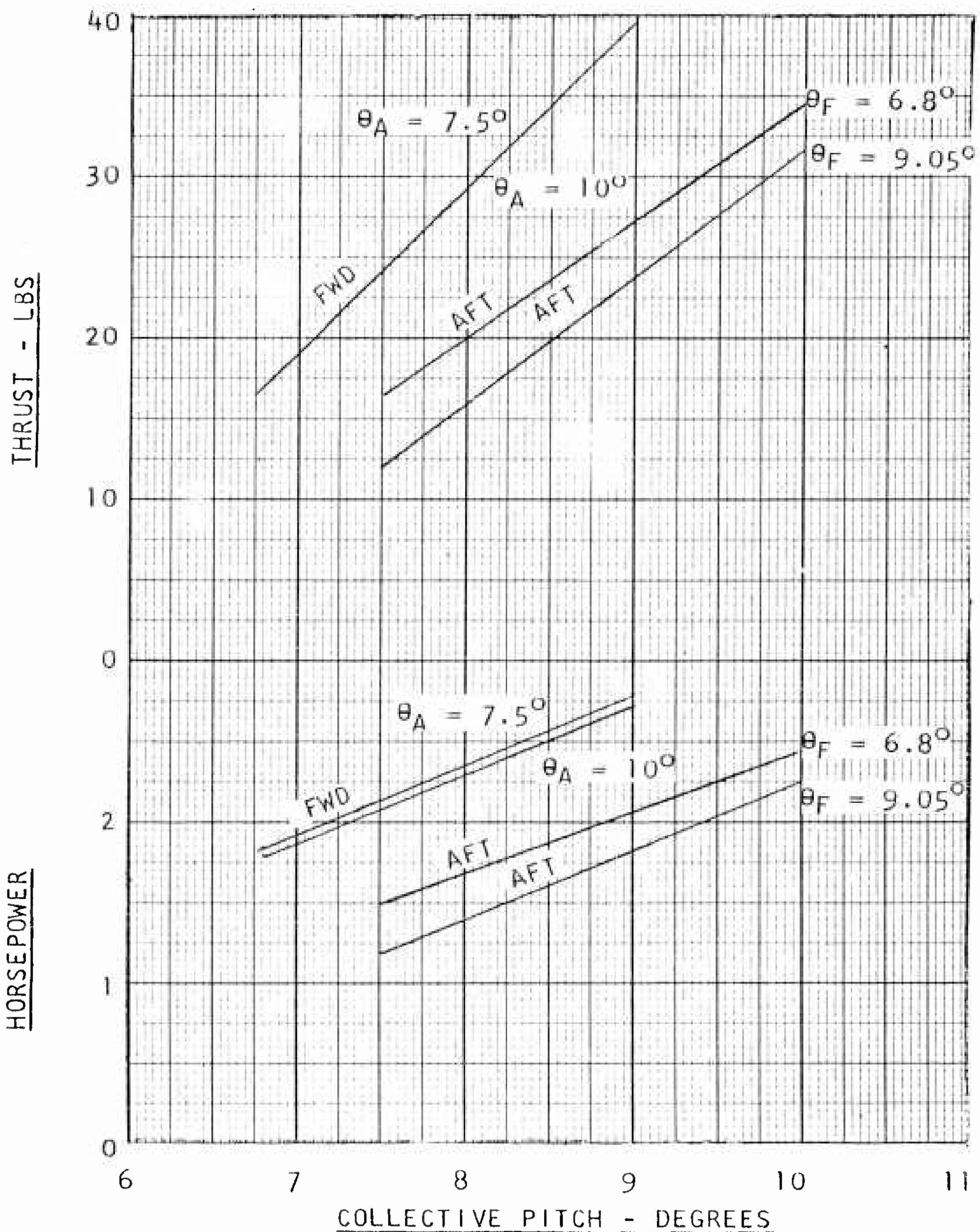


FIGURE 39

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH vs HORSEPOWER - THRUST
CONFIGURATION: WOODEN WING
SHAFT ANGLE OF ATTACK -12 DEG.
SPEED: 85 KTS.

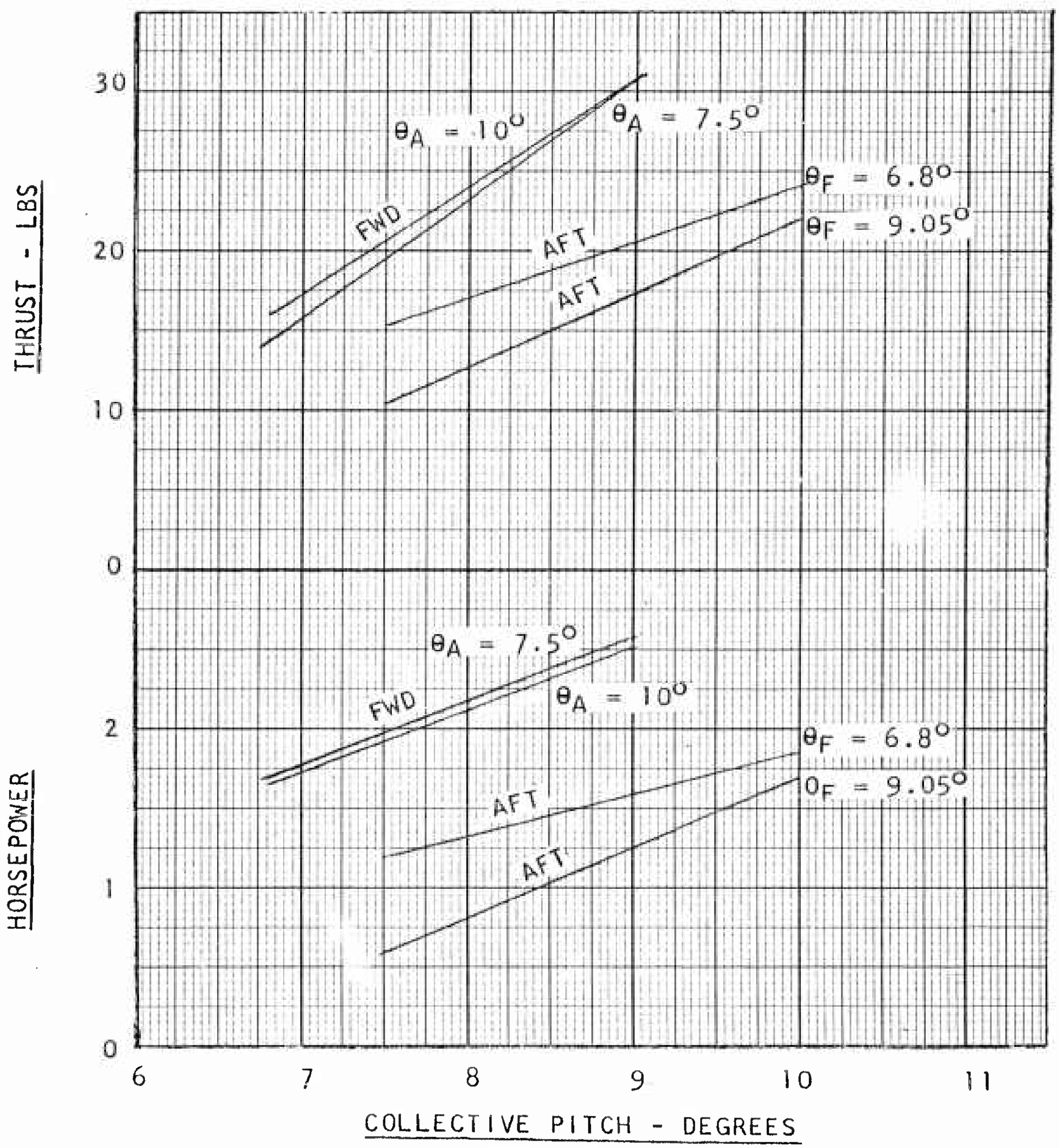


FIGURE 40

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH vs HORSEPOWER - THRUST
CONFIGURATION: METAL WING
SHAFT ANGLE OF ATTACK -12 DEG.
SPEED: 85 KTS.

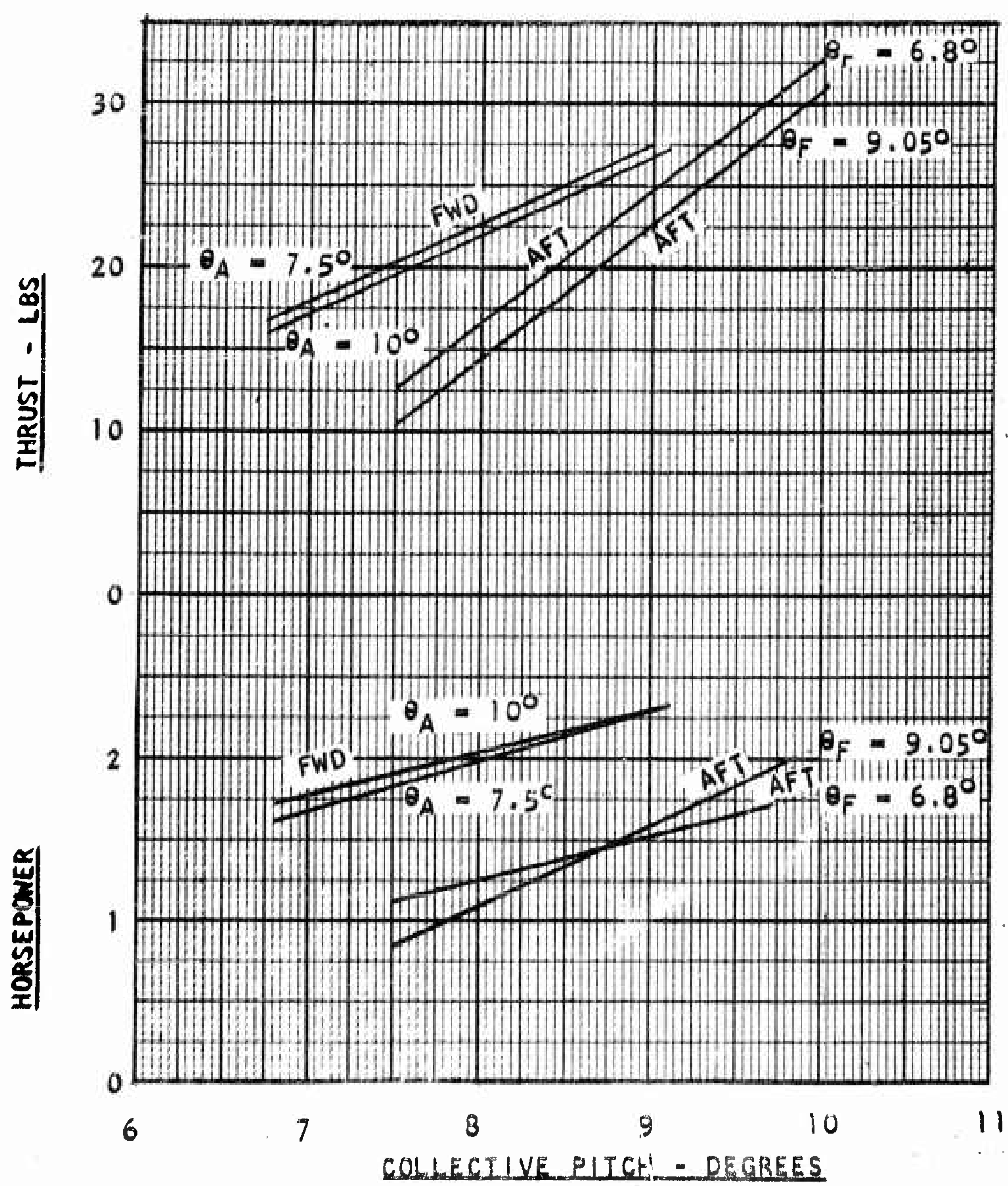


FIGURE 41

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH vs HORSEPOWER - THRUST
CONFIGURATION: NO WING
SHAFT ANGLE OF ATTACK -15 DEG.
SPEED: 85 KTS.

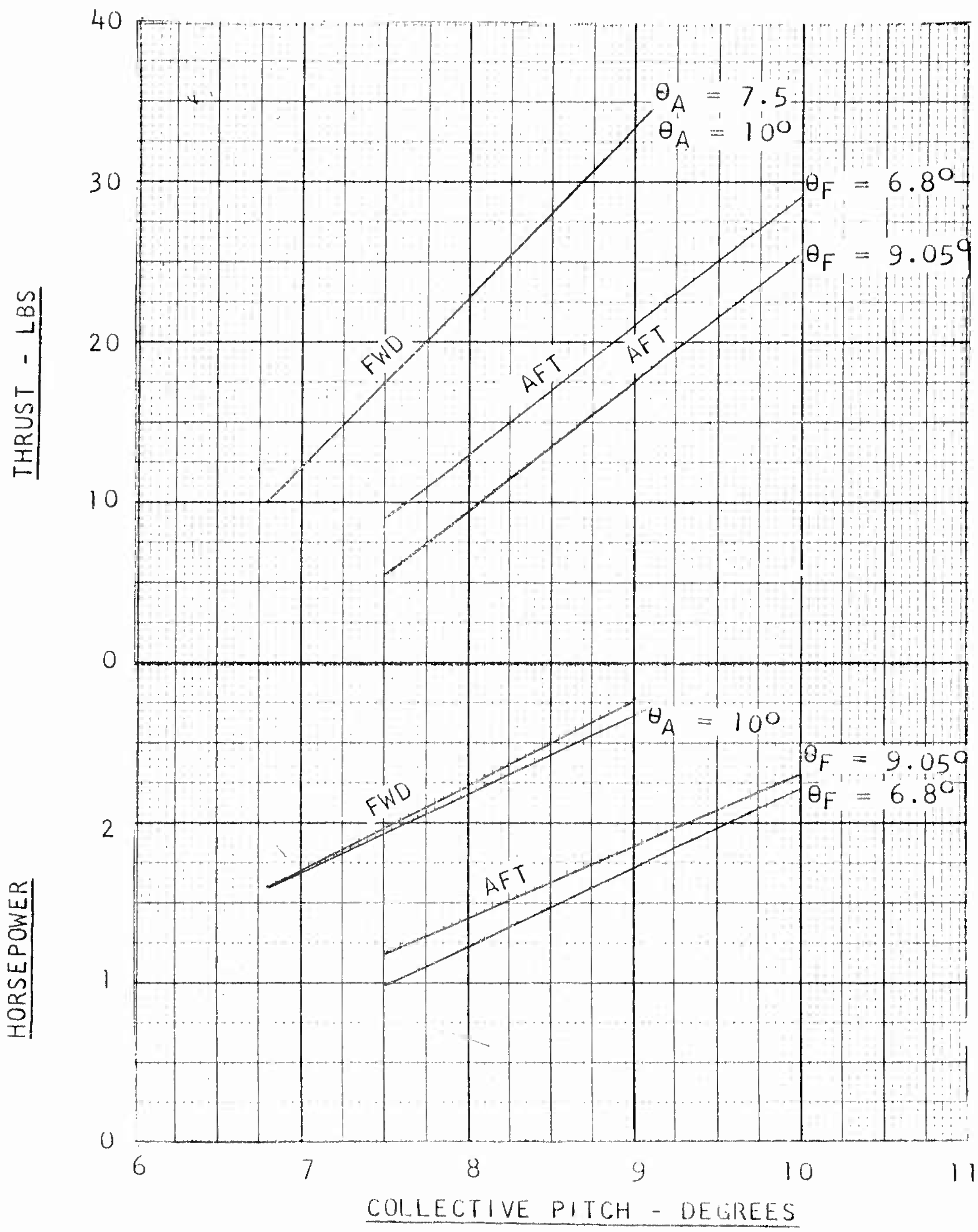


FIGURE 42

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH vs HORSEPOWER - THRUST
CONFIGURATION: WOODEN WING
SHAFT ANGLE OF ATTACK -15 DEG.
SPEED: 85 KTS.

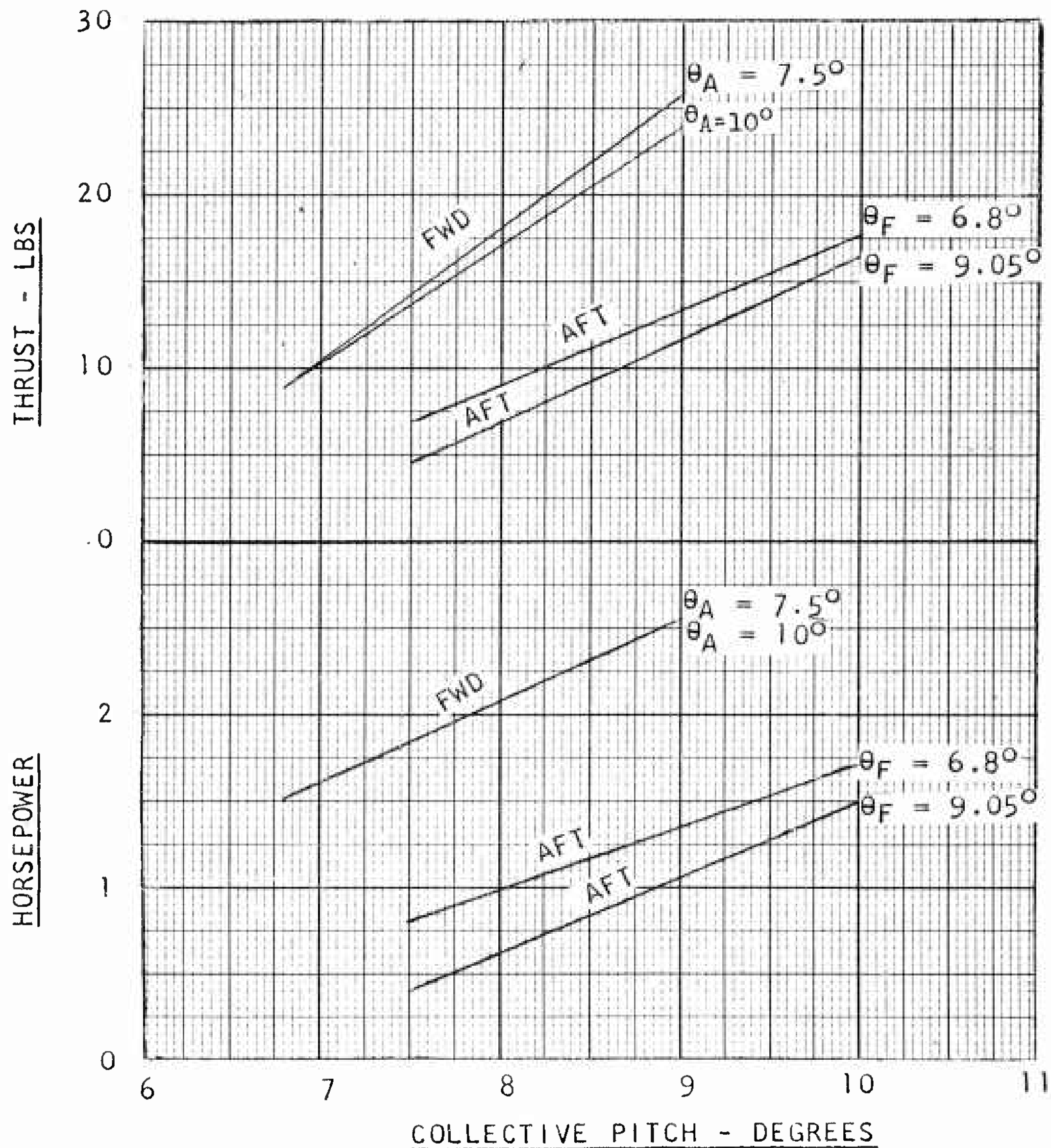


FIGURE 43

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY
COLLECTIVE PITCH vs HORSEPOWER - THRUST
CONFIGURATION: METAL WING
SHAFT ANGLE OF ATTACK -15 DEG.
SPEED: 85 KTS.

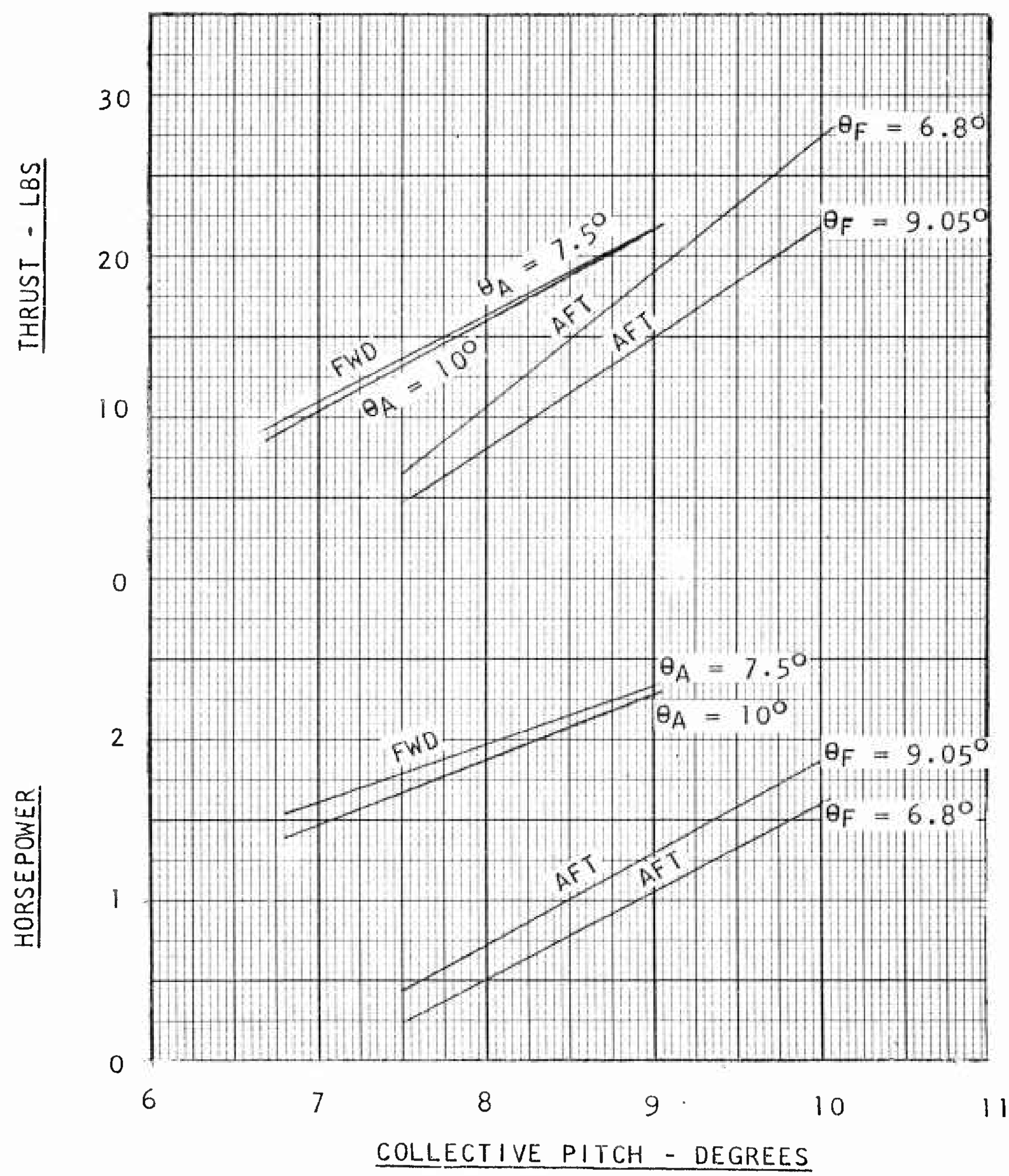


FIGURE 44

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

HORSEPOWER

NO WING vs WITH WING

FORWARD ROTOR

ROTOR DISK LOADING 2.86 lb/ft^2

TORQUE METER DATA

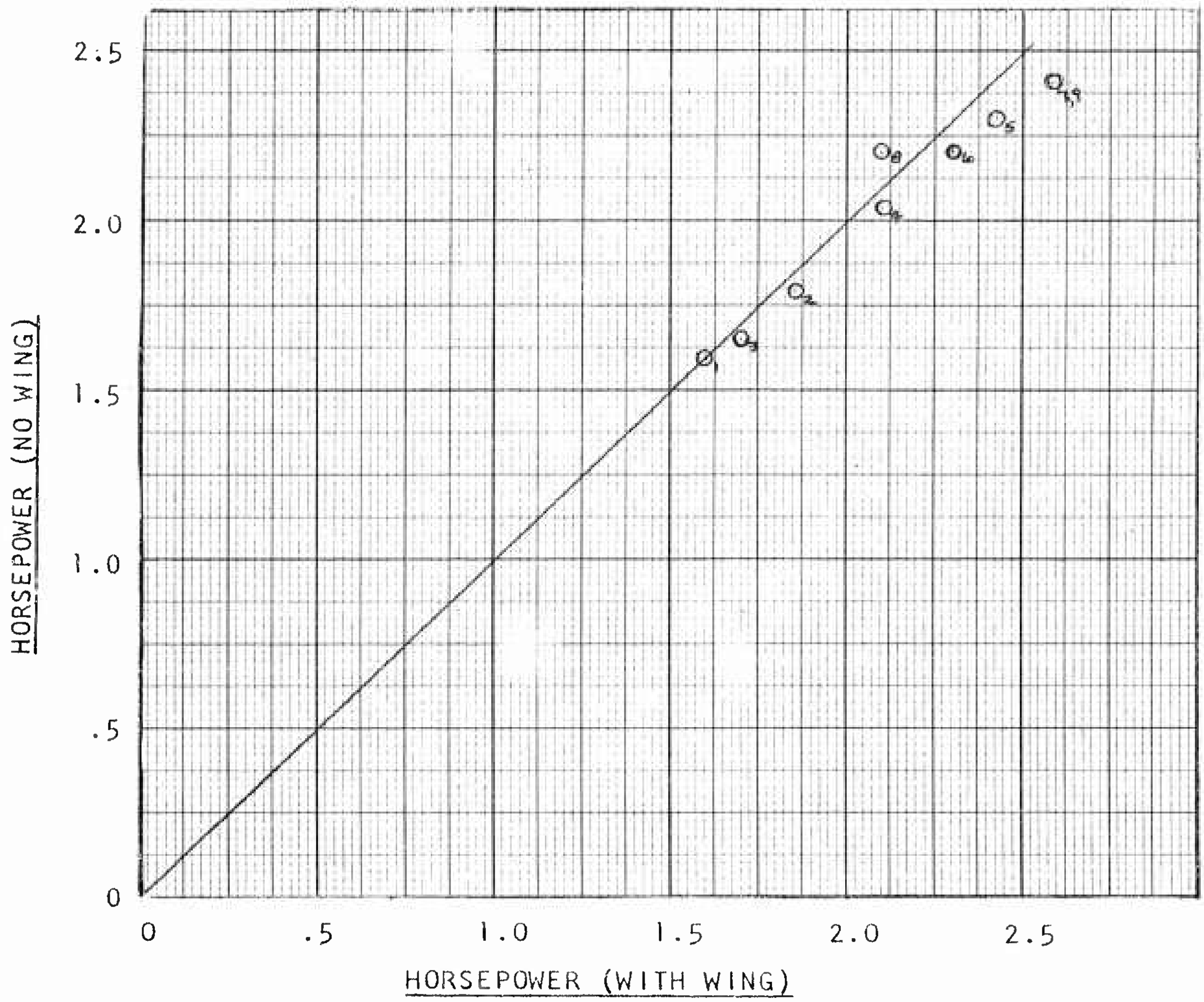


FIGURE 45

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

HORSEPOWER

NO WING vs WITH WING

REAR ROTOR

ROTOR DISK LOADING 2.86 lb/ft^2

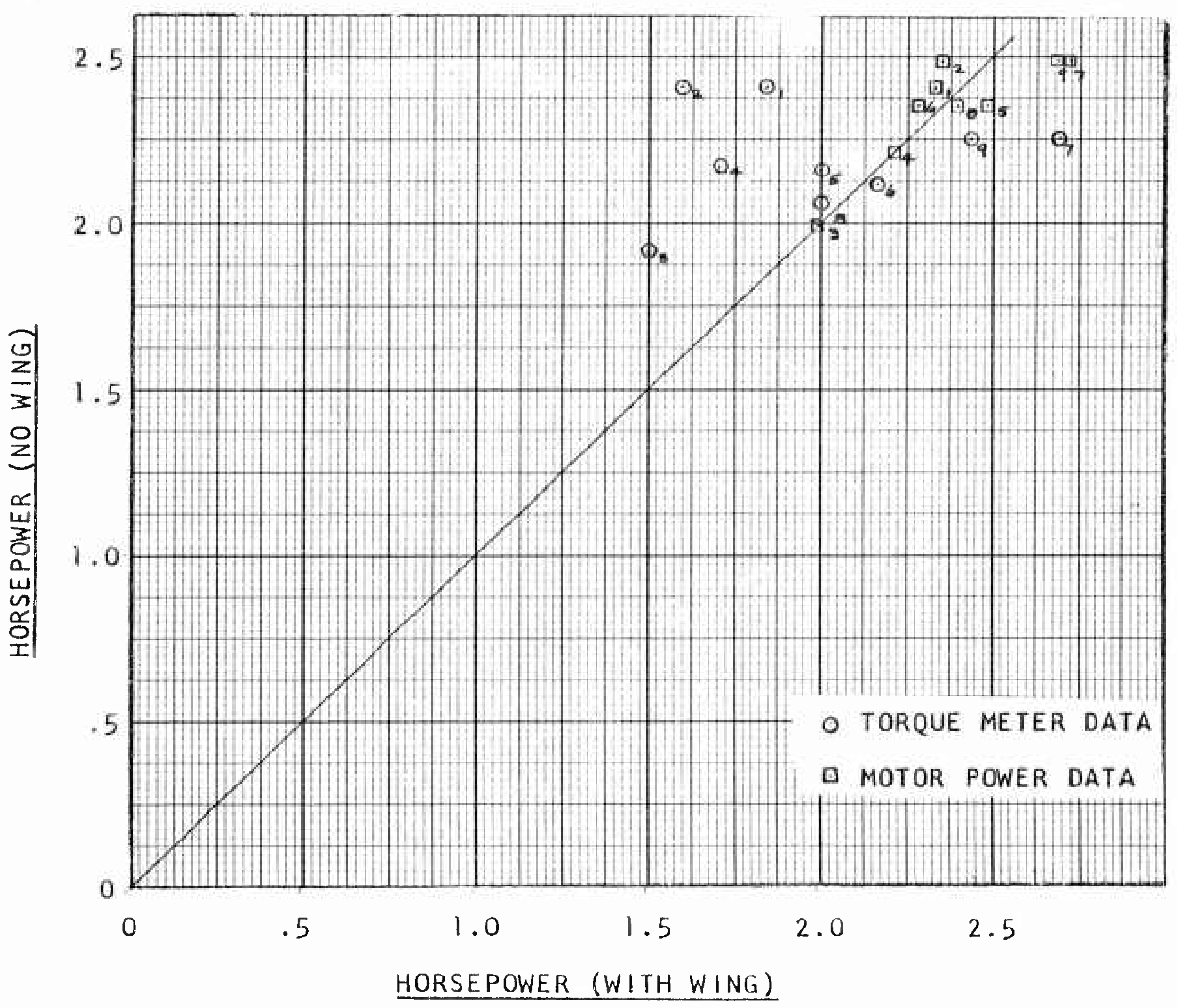


FIGURE 46

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

HORSEPOWER

NO WING vs WITH WING

TOTAL POWER

ROTOR DISK LOADING 2.86 lb/ft^2

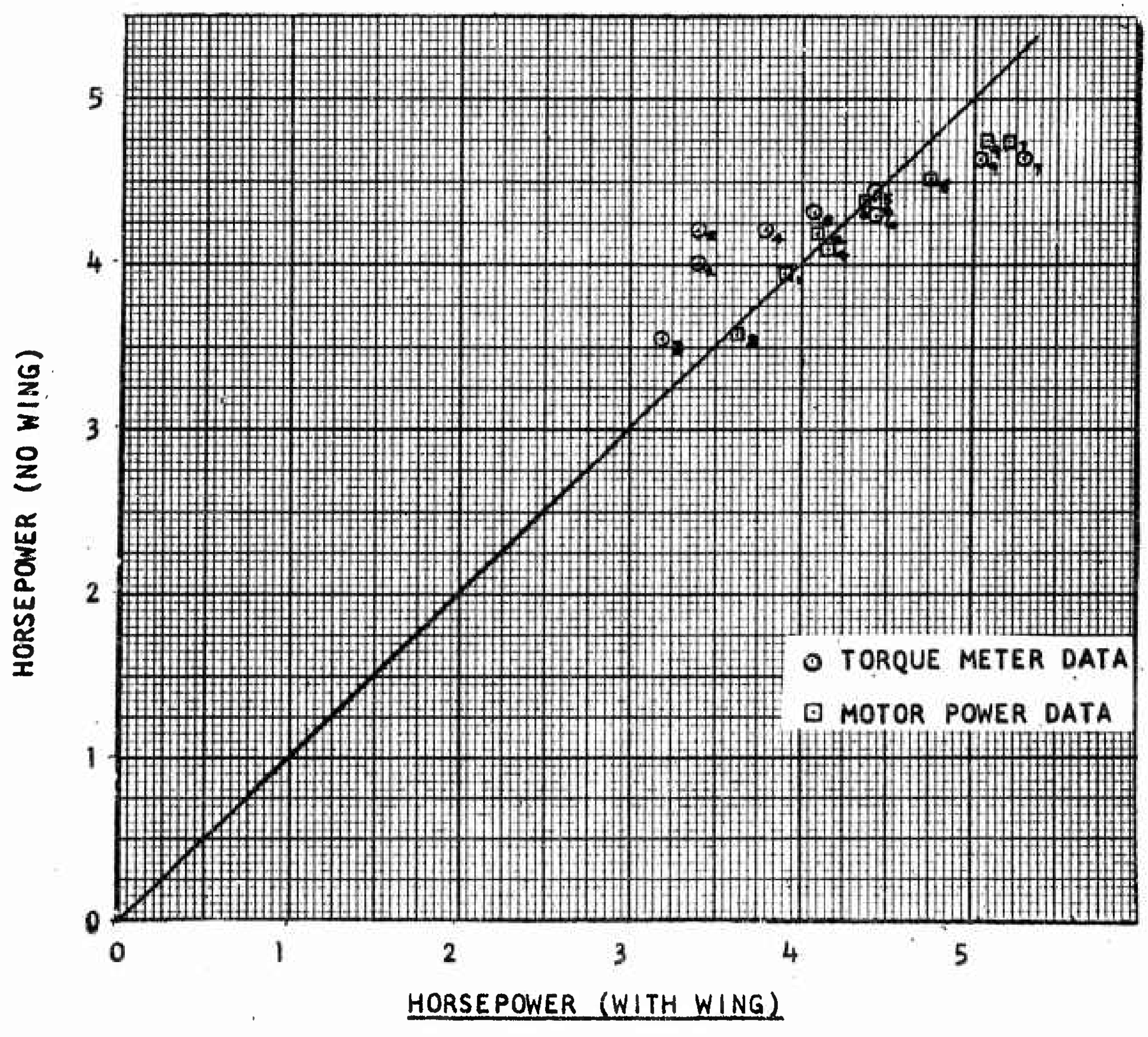


FIGURE 47

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

MODEL MOTOR CALIBRATION CURVE

TORQUE vs INPUT POWER

RPM = 5694

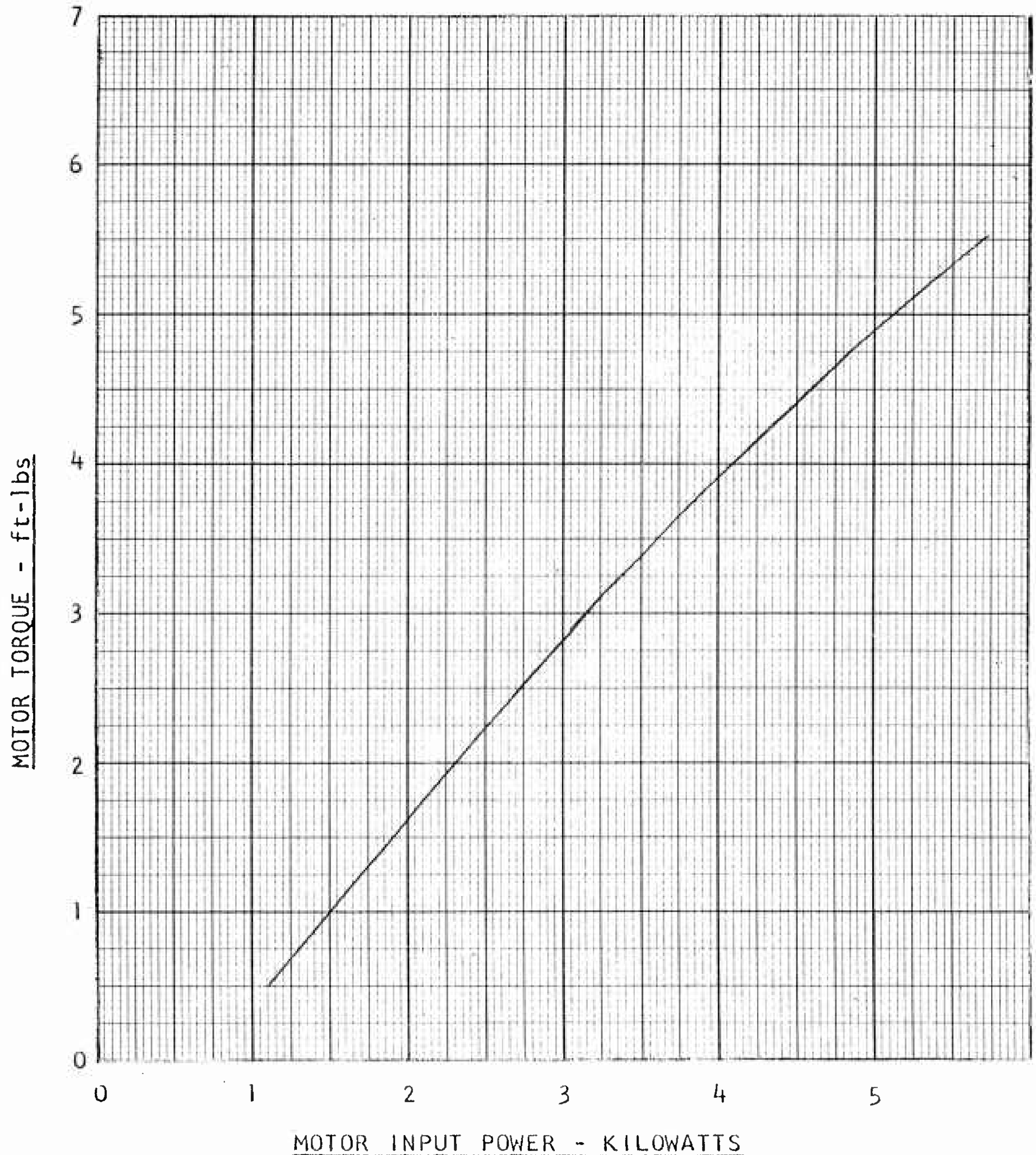


FIGURE 48

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

HORSEPOWER

NO WING vs WITH WING

FORWARD ROTOR

ROTOR DISC LOADING 2.86 lb/ft^2

POWER BASED ON COLLECTIVE PITCH

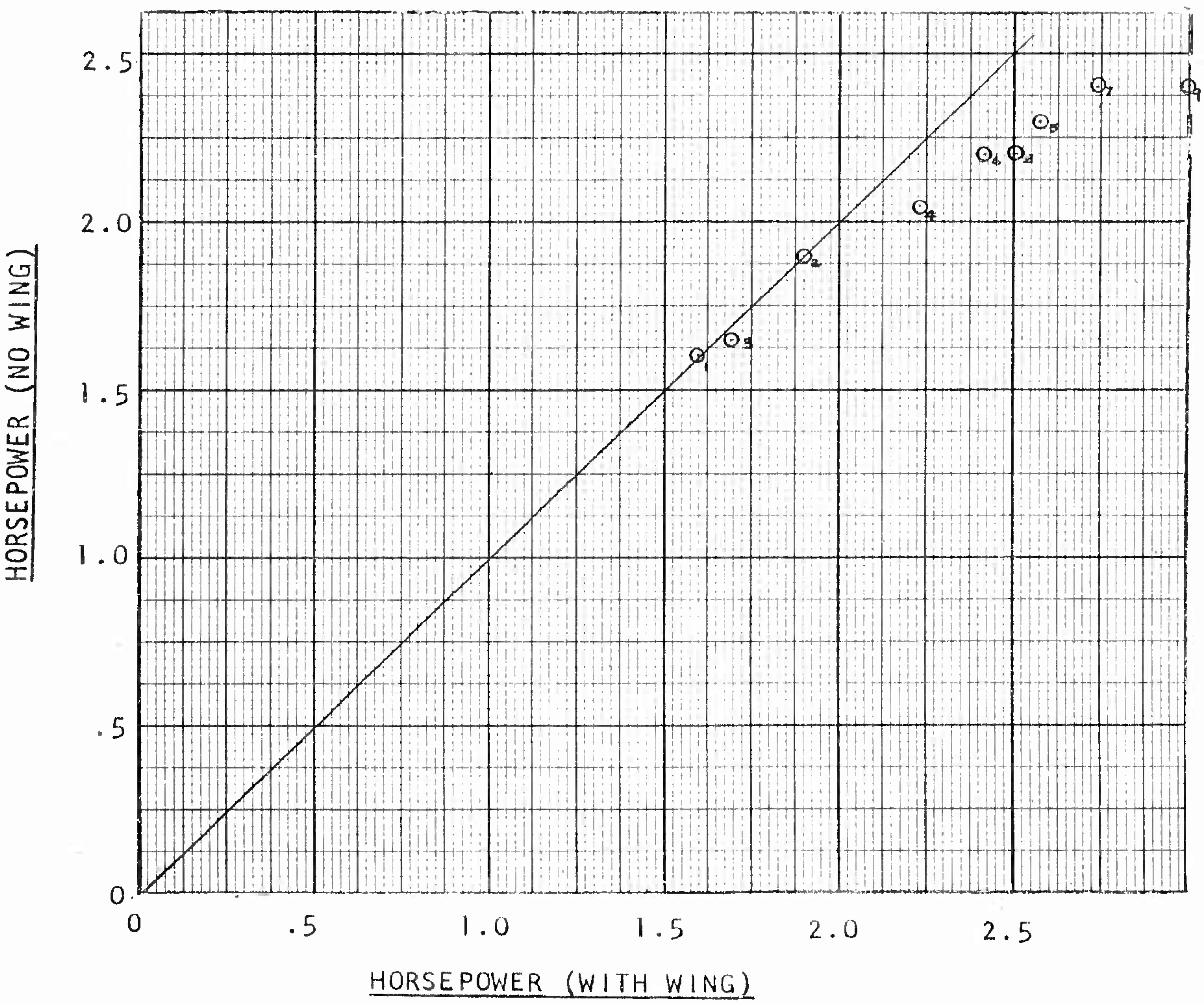


FIGURE 49

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

HORSEPOWER

NO WING VS. WITH WING

REAR ROTOR

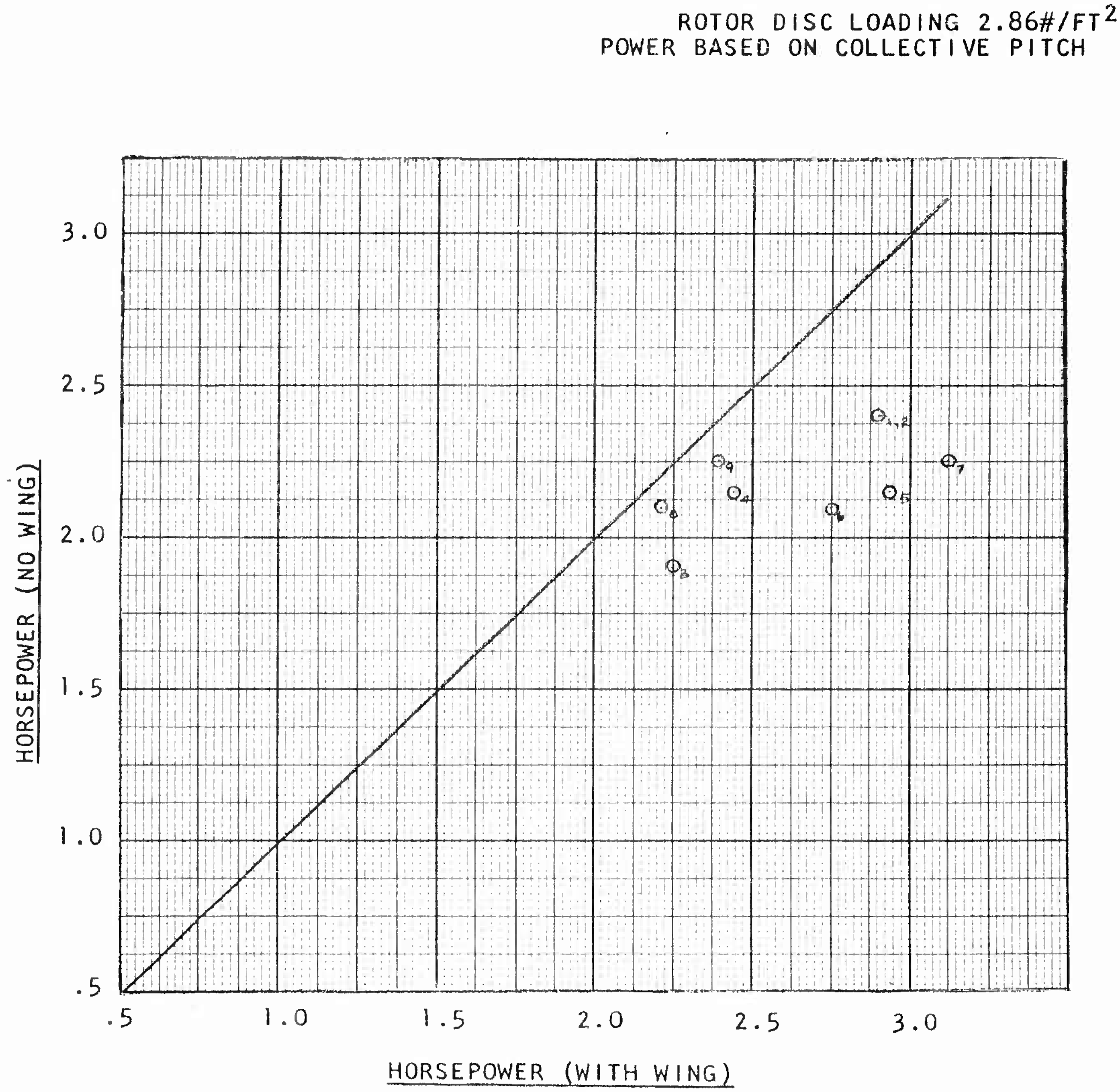


FIGURE 50

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

HORSEPOWER

NO WING VS. WITH WING

TOTAL POWER

ROTOR DISC LOADING 2.86#/FT^2
POWER BASED ON COLLECTIVE PITCH

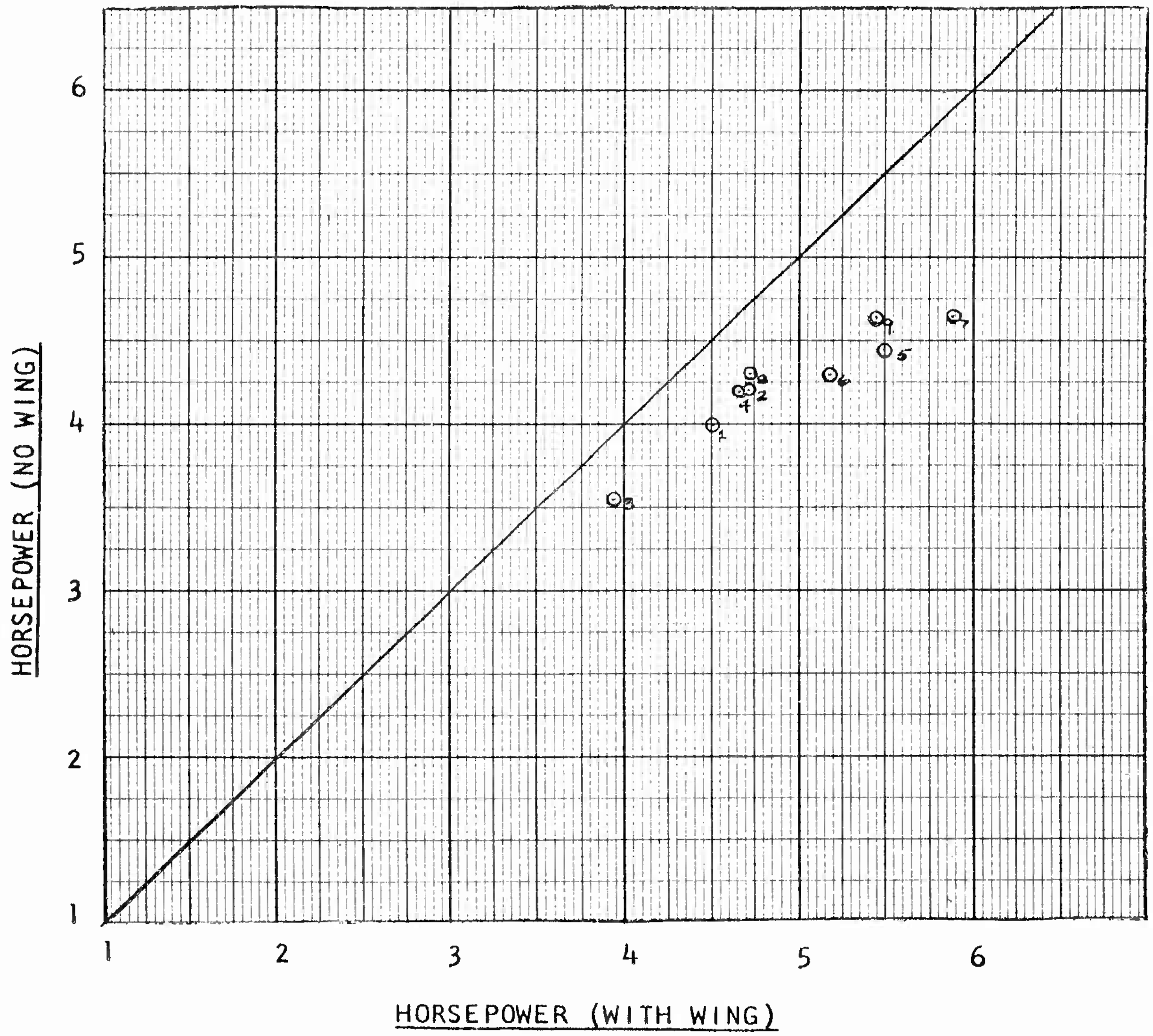


FIGURE 51

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

HORSEPOWER

NO WING VS. WITH WING

TOTAL POWER

ROTOR DISC LOADING 2.86#/FT^2

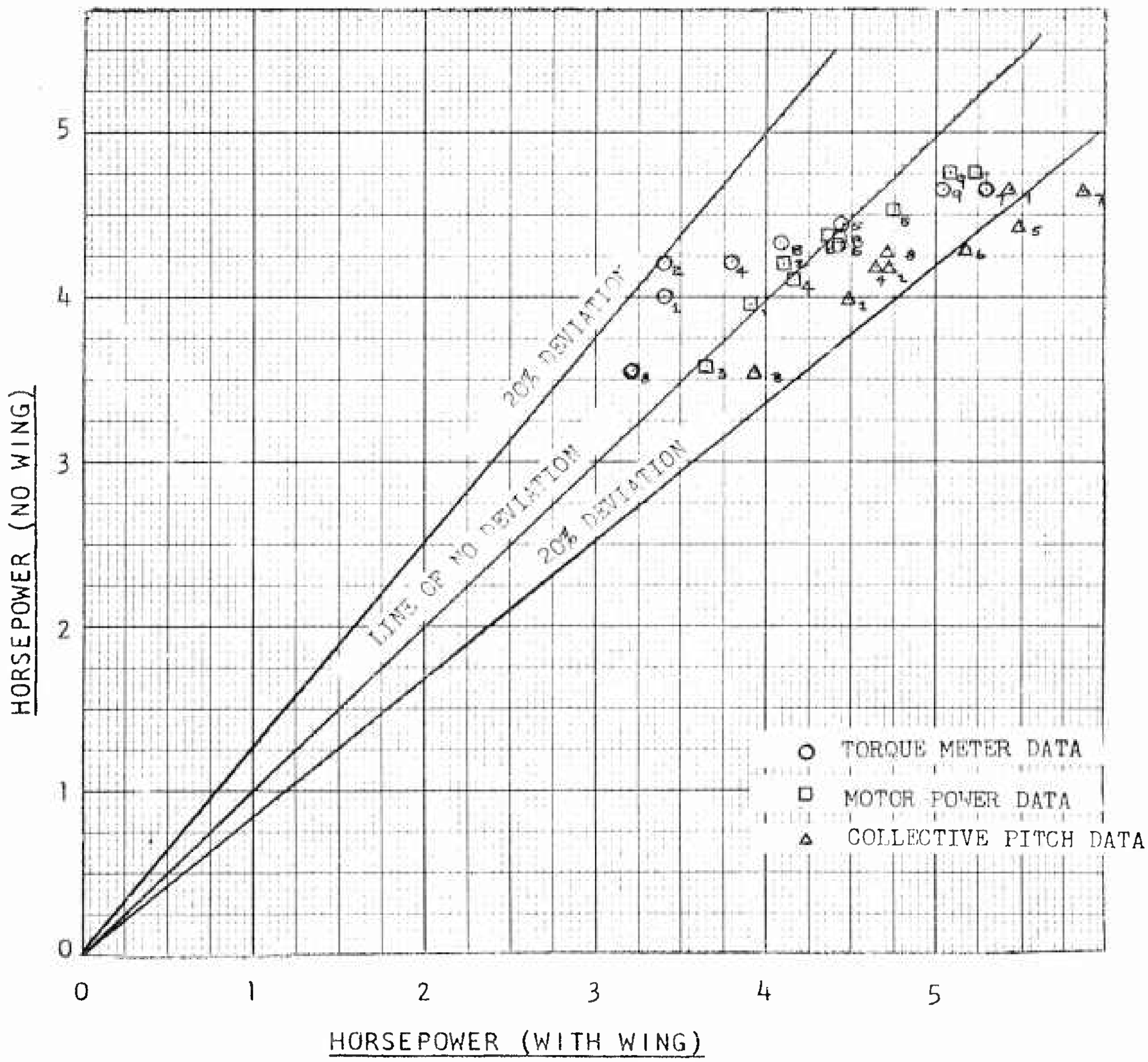


FIGURE 52

HELICOPTER RANGE EXTENSION STUDY

WING DYNAMIC RESPONSE

WOODEN WING

COLLECTIVE PITCH FWD. [illegible]
AFT 10.[illegible]

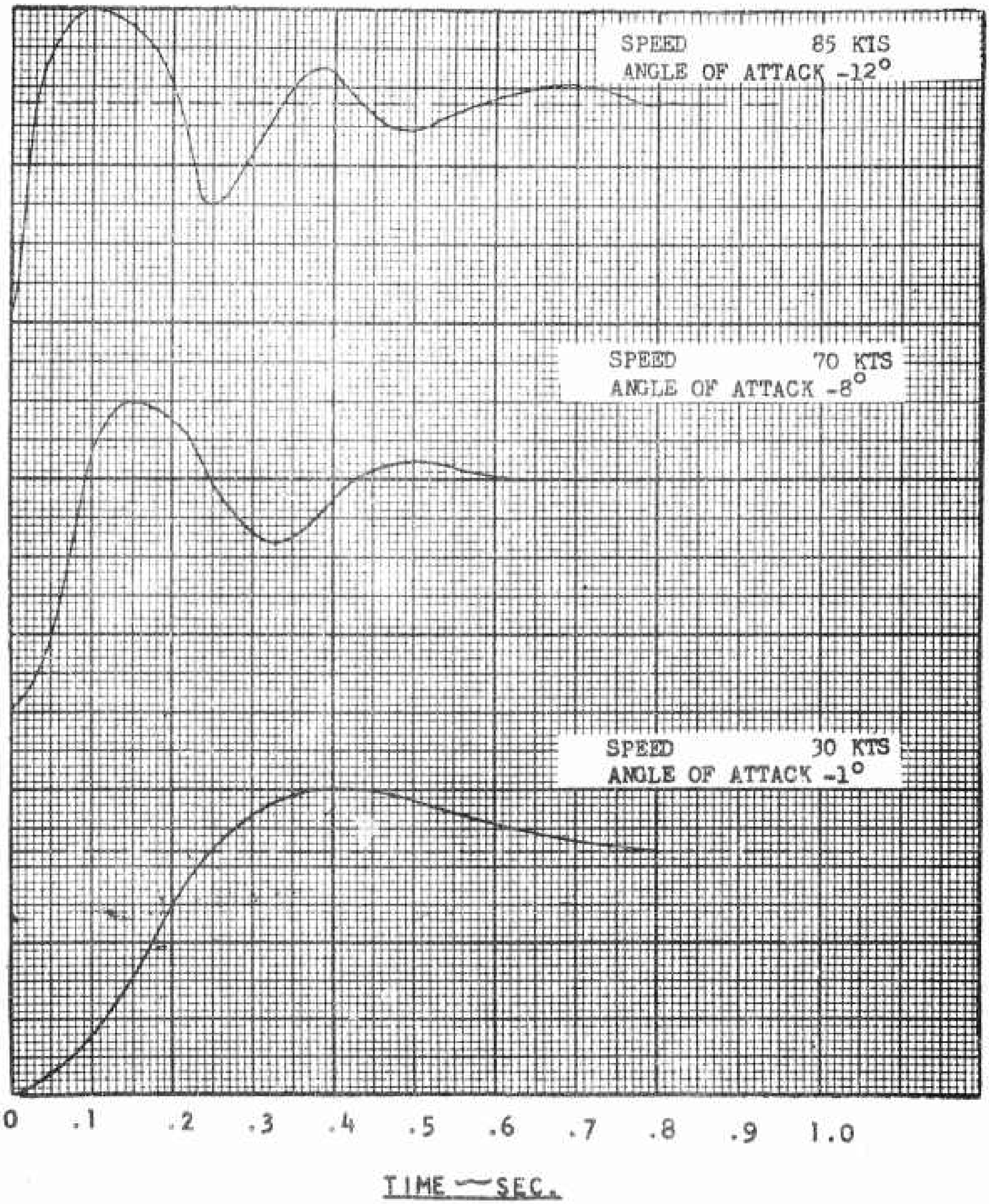


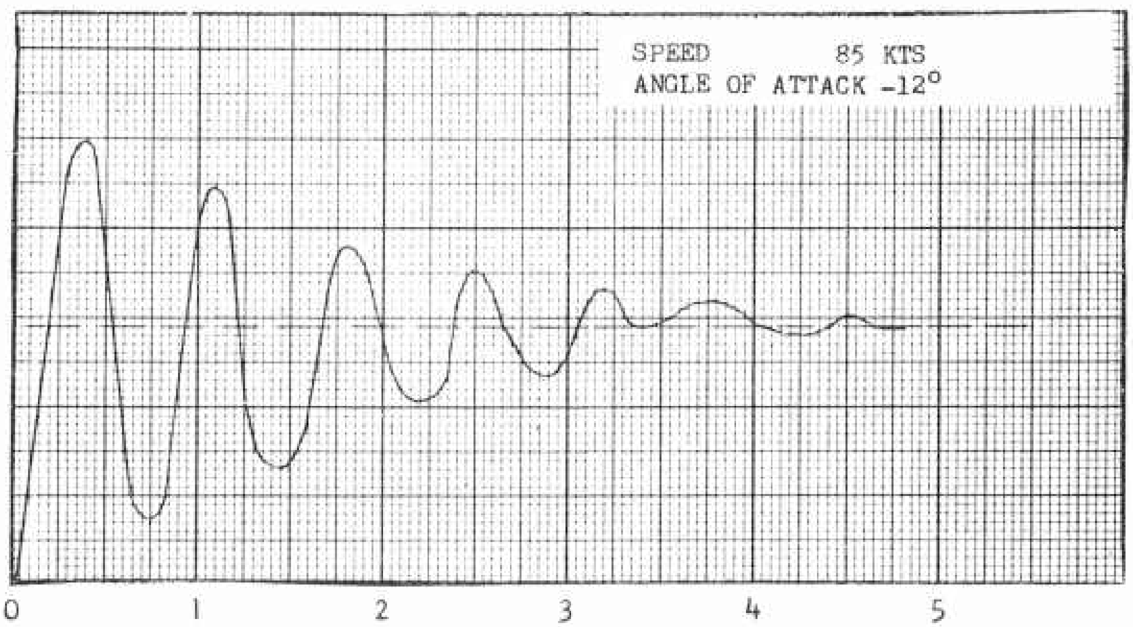
FIGURE 53

HELICOPTER RANGE EXTENSION STUDY

WING DYNAMIC RESPONSE

METAL WING

COLLECTIVE PITCH FWD. 9.05°
AFT 10.0°



TIME ~ SEC.

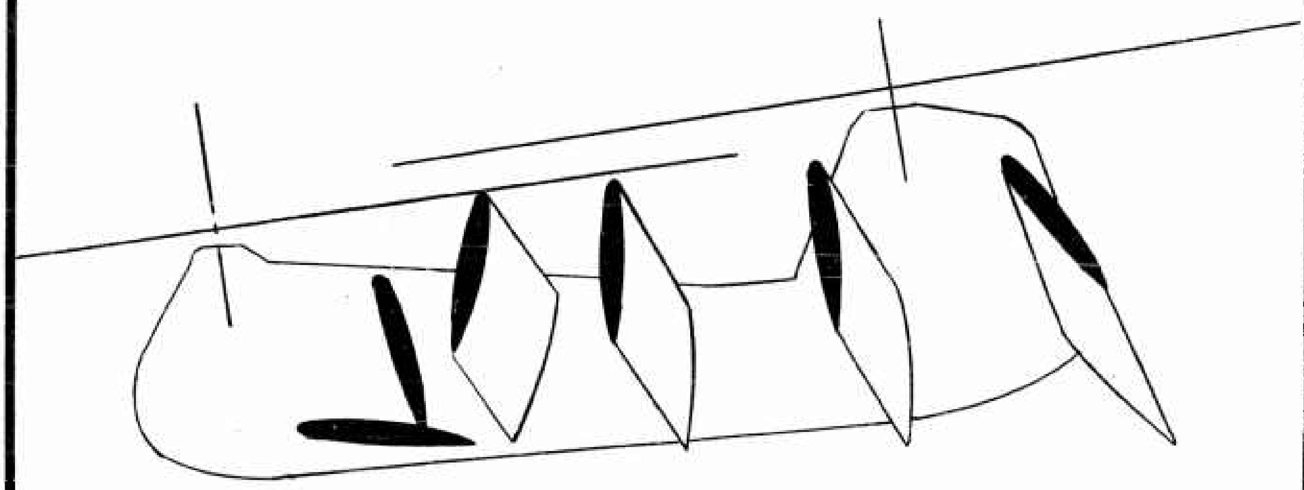
FIGURE 54

HELICOPTER RANGE EXTENSION STUDY

WING PANEL TRAJECTORY

Angle of Attack	$\alpha = -8.9^\circ$	
Collective Pitch	Fwd	6.8°
	Aft	7.5°
Speed	70 Knots	

WOODEN WING



REV

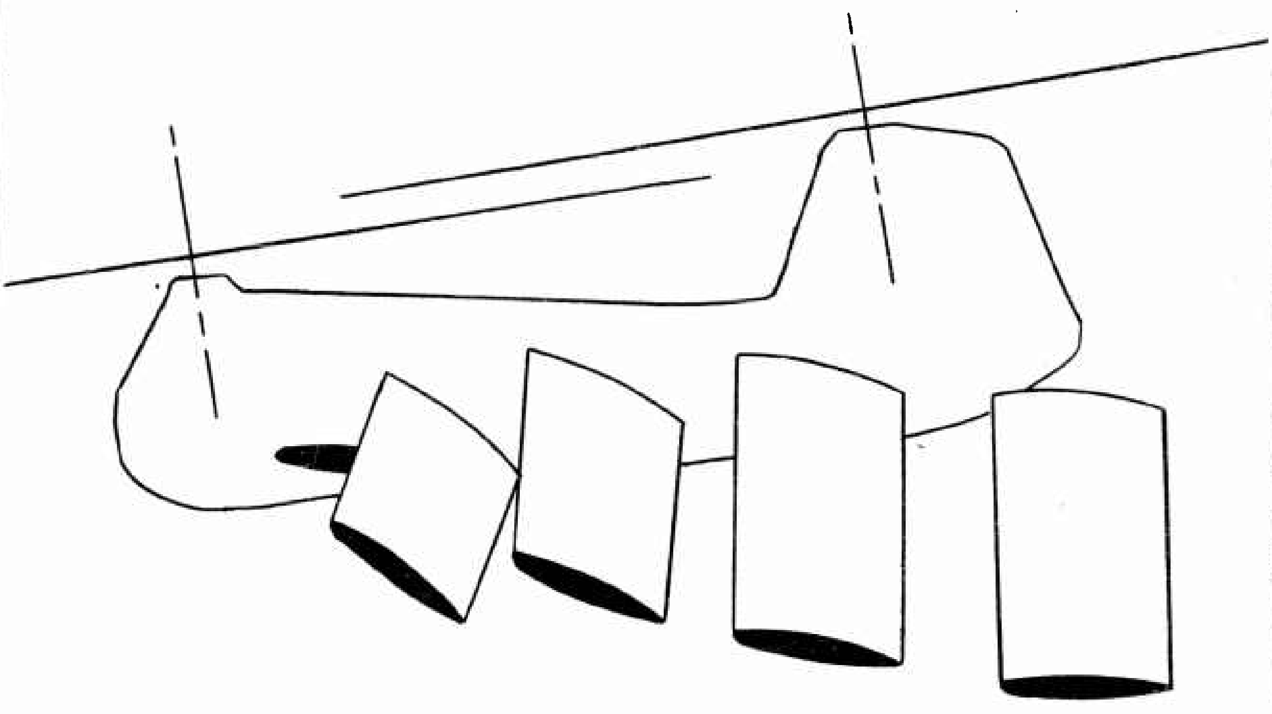
FIGURE 55

HELICOPTER RANGE EXTENSION STUDY

WING PANEL TRAJECTORY

Angle of Attack = -12°
Collective Pitch Fwd 6.8°
Aft 7.5°
Speed V = 85 Kts

METAL WING



REV

IX. LIST OF TABLES

REV

TABLE I

ACCURACY OF MEASURED FORCES AND MOMENTS

The errors introduced in reading the recorder tapes are as follows:

Lift	± 1 lb.	
Torque	±.4 ft.-lb.	(Aft)
	±.1 ft.-lb.	(Fwd)
Drag	±.2 lb.	
Power	±.05 hp	(Aft)
	±.02 hp	(Fwd)

Rotor RPM was held within .1%.

REV

TABLE 2

LEGEND

Point No.	Speed (Kts)	Angle of Attack (Deg)	Configuration
1	30	+ 1	Wood
2	30	- 1	Wood
3	70	- 5	Wood
4	70	- 8	Wood
5	70	-11	Wood
6	85	- 9	Wood
7	85	-12	Wood
8	85	- 9	Metal
9	85	-12	Metal

REV

TABLE 3

WING PANEL FREQUENCY RESPONSE

Collective Pitch Fwd 9.05°
Aft 10.0°

Where ω_n = Natural Frequency
ζ = Damping Ratio

Configuration	Model Measured		Full Scale Measured		Full Scale Calculated	
	ω_n	ζ	ω_n	ζ	ω_n	ζ
Wooden Wing						
V = 30 Kts	15	.38	5	(1.0)	3.3	.20
V = 70 Kts	37	.26	12.3	.78	7.7	.20
V = 85 Kts	24.6	.18	8.2	.54	9.3	.20
Metal Wing						
V = 85 Kts	8.65	.08	2.9	.24	3.4	.075

REV

TABLE 4

MODEL STABILITY DERIVATIVES

C_{m_α}

Velocity Knots	Shaft Angle of Attack Deg.	No Wing	Wooden Wing	Metal Wing
Collective Pitch Fwd 6.8° Aft 7.5°				
30	1	-.61	-.055	
70	-5	.12	.050	
70	-8	.053	-.057	
85	-9	.223	-.48	.483
85	-12	.227	.887	-.443
Collective Pitch Fwd 9.05° Aft 10.0°				
30	1	-.515	-2.77	
70	-5	-.023	.213	
70	-8	.233	-.79	
85	-9	.133	.41	.54
85	-12	.21	1.25	-.30

REV

TABLE 5

MODEL STABILITY DERIVATIVES

C_{m_μ}

Velocity Knots	Shaft Angle of Attack Deg.	No Wing	Wooden Wing	Metal Wing
Collective Pitch Fwd 6.8° Aft 7.5°				
30	1	.42.5	17.8	
30	-1	-14.6	33.0	
70	-8	6.9	26.3	
70	-11	-13.9	3.5	
85	-12	- 1.9	-43.1	95.1
85	-15	-27.3	124.3	126.8
Collective Pitch Fwd 9.05° Aft 10.0°				
30	1	13.0	8.2	
30	-1	-33.6	-22.1	
70	-8	2.2	12.7	
70	-11	8.2	17.4	
85	-12	-15.2	-4.4	-46.0
85	-15	-15.9	-19.7	8.9

REV

LIST OF SYMBOLS

A	Area of rotor (πR^2)
a, C_{L_α}	Slope-lift coefficient vs. angle of attack
C	Damping constant
C_{m_μ}	Change in moment coefficient with respect to a change in advance ratio.
C_{m_α}	Change in moment coefficient with respect to a change in attitude.
C_Z	Nondimensionalize tunnel balance system force in Z direction ($C_Z = \frac{Z}{\rho 2\pi R^2 V_T^2}$)
C_X	Nondimensionalize tunnel balance system force in X direction ($C_X = \frac{X}{\rho 2\pi R^2 V_T^2}$)
C_M	Nondimensionalize tunnel balance system moment in pitching plane ($C_M = \frac{M}{\rho 2\pi R^3 V_T^2}$
C_T	Thrust coefficient
d_f	Interference factor $f(\gamma_s)$
HP	Horsepower
ΔHP	Difference between forward rotor horsepower and rear rotor horsepower
I	Moment of inertia of wing about skewed hinge line
i_ϵ	The angle subtended by a line through the front and rear hubs and X axis
K	Spring constant
ℓ_1	Perpendicular distance from hinge line to wing C.G.
ℓ_m	Length of model
ℓ_{FS}	Length of full scale
q	Dynamic pressure

REV

LIST OF SYMBOLS - (CONTINUED)

R	Model rotor radius
S	Wing panel area
S.F.	Scale Factor
T	Thrust
ΣT	Summarization of forward and aft rotor thrust
T_1	Function of μ
T_2	Function of μ
V_o, V	Forward Velocity
V_T	Velocity of rotor tip
v	Induced velocity
Z	Tunnel balance system force in Z direction
α	Angle of attack of shaft with vertical plane
γ_s	$= i_\epsilon - \alpha + \tan^{-1} \frac{T_F}{2qA}$
δ	Skewed hinge angle
ζ	Damping ratio
θ	Collective pitch
θ	Coning angle of wing about hinge
$\dot{\theta}$	Angular velocity of wing about hinge
$\ddot{\theta}$	Angular acceleration of wing about hinge
$\Delta\theta$	Difference between forward rotor collective pitch and rear rotor collective pitch
λ	Inflow ratio
μ	Ratio forward velocity to rotor tip speed
ρ	Density

REV

LIST OF SYMBOLS - (CONTINUED)

σ	Solidity Ratio
ω_n	Natural Frequency

SUBSCRIPTS

A, R	Rear rotor
F	Forward rotor

REV

APPENDIX A

A detailed test program of the helicopter range extension system is presented in the following appendix. It should be noted that the test points involving the metal wing were run at 85 and 90 knots only. The metal wing would not support itself due to Reynold's number, presence of rotor, etc., at speeds lower than 85 knots.

REV

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

WIND TUNNEL PROGRAM

RUN NO.	CONFIGURATION WING None	Wood	Metal	COLLECTIVE PITCH SET NO. 1	2	3	4	TUNNEL SPEED Kts	q	MODEL ANGLE OF ATTACK α_f Deg.	YAW ANGLE Deg.	WING ATTITUDE Deg.	FLAP ANGLE Deg.	PURPOSE
1	X			X				30	3.05	1	0			Helicopter Power & Stability Information
2	X			X				30	3.05	-1	0			
3	X			X				40	5.43	1	0			
4	X			X				40	5.43	-1	0			
5	X			X				70	16.6	-5	0			
6	X			X				70	16.6	-8	0			
7	X			X				70	16.6	-11	0			
8	X			X				80	21.7	-8	0			
9	X			X				80	21.7	-11	0			
10	X			X				85	24.6	-9	0			
11	X			X				85	24.6	-12	0			
12	X			X				85	24.6	-15	0			
13	X			X				90	27.5	-12	0			
14	X			X				90	27.5	-15	0			
15	X			X				85	24.6	-9	5			Yaw Stability Derivatives
16	X			X				85	24.6	-15	5			
17	X			X				85	24.6	-15	10			
18	X			X				85	24.6	-9	10			
19	X				X			30	3.05	1	0			
20	X				X			30	3.05	-1	0			
21	X				X			70	16.6	-5	0			
22	X				X			70	16.6	-8	0			
23	X				X			70	16.6	-11	0			
24	X				X			85	24.6	-9	0			
25	X				X			85	24.6	-12	0			
26	X				X			85	24.6	-15	0			
27	X					X		30	3.05	1	0			Helicopter Power & Stability Information
28	X					X		30	3.05	-1	0			
29	X					X		40	5.43	1	0			
30	X					X		40	5.43	-1	0			
31	X					X		70	16.6	-5	0			
32	X					X		70	16.6	-8	0			
33	X					X		70	16.6	-11	0			
34	X					X		80	21.7	-8	0			
35	X					X		80	21.7	-11	0			
36	X					X		85	24.6	-9	0			
37	X					X		85	24.6	-12	0			
38	X					X		85	24.6	-15	0			
39	X					X		90	27.5	-12	0			
40	X					X		90	27.5	-15	0			
41	X						X	30	3.05	1	0			
42	X						X	30	3.05	-1	0			
43	X						X	70	16.6	-5	0			
44	X						X	70	16.6	-8	0			
45	X						X	70	16.6	-11	0			
46	X						X	85	24.6	9	0			
47	X						X	85	24.6	-12	0			
48	X						X	85	24.6	-15	0			
49		X		X				30	3.05	1	0	0	-	
50		X		X				30	3.05	-1	0	-	(49)	
51		X		X				30	3.05	-1	0	0	-	
52		X		X				40	5.43	1	0	-	(49)	Low Wing Loading Power & Stability Information
53		X		X				40	5.43	-1	0	-	(51)	
54		X		X				70	16.6	-5	0	0	-	
55		X		X				70	16.6	-8	0	-	(54)	
56		X		X				70	16.6	-8	0	0	-	
57		X		X				70	16.6	-11	0	-	(56)	
58		X		X				70	16.6	-11	0	0	-	
59		X		X				80	21.7	-8	0	-	(56)	
60		X		X				80	21.7	-11	0	-	(58)	
61		X		X				85	24.6	-9	0	0	-	
62		X		X				85	24.6	-12	0	-	(61)	
63		X		X				85	24.6	-12	0	0	-	
64		X		X				85	24.6	-15	0	-	(63)	
65		X		X				85	24.6	-15	0	0	-	

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

WIND TUNNEL PROGRAM

RUN NO.	CONFIGURATION WING None	Wood	Metal	COLLECTIVE PITCH SET NO. 1	2	3	4	TUNNEL SPEED Kts	q	MODEL ANGLE OF ATTACK α_F Deg.	YAW ANGLE Deg.	WING ATTITUDE Deg.	FLAP ANGLE Deg.	PURPOSE
66		X		X				90	27.5	-12	0	-	(63)	Yaw Stability Derivatives
67		X		X				90	27.5	-15	0	-	(65)	
68		X		X				85	24.6	-9	5	-	(61)	
69		X		X				85	24.6	-15	5	-	(65)	
70		X		X				85	24.6	-15	10	-	(65)	
71		X		X				85	24.6	-9	10	-	(61)	
72		X			X			30	3.05	1	0	0	-	
73		X			X			30	3.05	-1	0	0	-	
74		X			X			70	16.6	-5	0	0	-	
75		X			X			70	16.6	-8	0	0	-	
76		X			X			70	16.6	-11	0	0	-	
77		X			X			85	24.6	-9	0	0	-	
78		X			X			85	24.6	-12	0	0	-	
79		X			X			85	24.6	-15	0	0	-	
80		X				X		30	3.05	1	0	0	-	
81		X				X		30	3.05	-1	0	-	(80)	Low Wing Loading Power & Stability Information
82		X				X		30	3.05	-1	0	0	-	
83		X				X		40	5.43	1	0	-	(80)	
84		X				X		40	5.43	-1	0	-	(82)	
85		X				X		70	16.6	-5	0	0	-	
86		X				X		70	16.6	-8	0	-	85	
87		X				X		70	16.6	-8	0	0	-	
88		X				X		70	16.6	-11	0	-	(87)	
89		X				X		70	16.6	-11	0	0	-	
90		X				X		80	21.7	-8	0	-	(87)	
91		X				X		80	21.7	-11	0	-	(89)	
92		X				X		85	24.6	-9	0	0	-	
93		X				X		85	24.6	-12	0	-	(92)	
94		X				X		85	24.6	-12	0	0	-	
95		X				X		85	24.6	-15	0	-	(94)	
96		X				X		85	24.6	-15	0	0	-	
97		X				X		90	27.5	-12	0	-	(94)	
98		X				X		90	27.5	-15	0	-	(96)	
99		X					X	30	3.05	1	0	0	-	
100		X					X	30	3.05	-1	0	0	-	
101		X					X	70	16.6	-5	0	0	-	
102		X					X	70	16.6	-8	0	0	-	
103		X					X	70	16.6	-11	0	0	-	
104		X					X	85	24.6	-9	0	0	-	
105		X					X	85	24.6	-12	0	0	-	
106		X					X	85	24.6	-15	0	0	-	
107			X	X				70	16.6	-5	0	0	-	
108			X	X				70	16.6	-8	0	-	(102)	
109			X	X				70	16.6	-8	0	0	-	
110			X	X				70	16.6	-11	0	-	(109)	
111			X	X				70	16.6	-11	0	0	-	High Wing Loading Power & Stability Information
112			X	X				80	21.7	-8	0	-	(109)	
113			X	X				80	21.7	-11	0	-	(111)	
114			X	X				85	24.6	-9	0	0	-	
115			X	X				85	24.6	-12	0	-	(114)	
116			X	X				85	24.6	-12	0	0	-	
117			X	X				85	24.6	-15	0	-	(116)	
118			X	X				85	24.6	-15	0	0	-	
119			X	X				90	27.5	-12	0	-	(116)	
120			X	X				90	27.5	-15	0	-	(118)	
121			X		X			70	16.6	-5	0	0	-	
122			X		X			70	16.6	-8	0	0	-	
123			X		X			70	16.6	-11	0	0	-	
124			X		X			85	24.6	-9	0	0	-	
125			X		X			85	24.6	-12	0	0	-	
126			X		X			85	24.6	-15	0	0	-	
127			X			X		70	16.6	-5	0	0	-	
128			X			X		70	16.6	-8	0	-	(127)	
129			X			X		70	16.6	-8	0	0	-	
130			X			X		70	16.6	-11	0	-	(129)	

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

WIND TUNNEL PROGRAM

RUN NO.	CONFIGURATION WING None	Wood	Metal	COLLECTIVE PITCH SET NO. 1	2	3	4	TUNNEL SPEED Kts	q	MODEL ANGLE OF ATTACK α_F Deg.	YAW ANGLE Deg.	WING ATTITUDE Deg.	FLAP ANGLE Deg.	PURPOSE
131			X			X		70	16.6	-11	0	0	-	High Wing Loading Power & Stability Information
132			X			X		80	21.7	-8	0	-	(129)	
133			X			X		80	21.7	-11	0	-	(131)	
134			X			X		85	24.6	-9	0	0	-	
135			X			X		85	24.6	-12	0	-	(134)	
136			X			X		85	24.6	-12	0	0	-	
137			X			X		85	24.6	-15	0	-	(136)	
138			X			X		85	24.6	-15	0	0	-	
139			X			X		90	27.5	-12	0	-	(136)	
140			X			X		90	27.5	-15	0	-	(138)	
141			X				X	70	16.6	-5	0	0	-	
142			X				X	70	16.6	-8	0	0	-	
143			X				X	70	16.6	-11	0	0	-	
144			X				X	85	24.6	-9	0	0	-	
145			X				X	85	24.6	-12	0	0	-	
146			X				X	85	24.6	-15	0	0	-	
147			X	X				70	16.6	-8	0	f(t)	(109)	Wing Dynamics
148			X	X				85	24.6	-12	0	f(t)	(116)	
149		X		X				30	3.05	-1	0	f(t)	(51)	
150		X		X				70	16.6	-8	0	f(t)	(56)	
151		X		X				85	24.6	-12	0	f(t)	(63)	
152	X			X				30	3.05	+1	0			In-Ground Effect
153	X			X				30	3.05	-1	0			
154	X			X				70	16.6	-5	0			
155	X			X				70	16.6	-8	0			
156	X			X				70	16.6	-11	0			
157		X		X				30	3.05	1	0	0	-	
158		X		X				30	3.05	-1	0	0	-	
159			X	X				70	16.6	-5	0	0	-	
160			X	X				70	16.6	-8	0	0	-	
161			X	X				70	16.6	-11	0	0	-	
162		X						70	16.6	-8	0	0	-	
163			X					70	16.6	-8	0	0	-	Jettison Test
164		X		X				70	16.6	-8	0	0	-	
165			X	X				70	16.6	-8	0	0	-	

COLLECTIVE PITCH LEGEND

Set No.	Indicated Fwd. (Deg)	Indicated Aft (Deg)	Corrected Fwd. (Deg)	Corrected Aft (Deg)
1	7	9	6.8	7.5
2	10	9	9.05	7.5
3	10	12	9.05	10
4	7	12	6.8	10

REV

APPENDIX B

Theoretical derivations and their associated figures are presented in this appendix as follows:

(1) Derivation of forward and rear theoretical rotor thrust including interference effect on rear rotor for standard helicopter configuration.

(2) Derivation of change in power based on change in collective pitch. Fig. A & B indicates increase in collective pitch necessary to obtain rotor power for helicopter-wing combination.

(3) Derivation of equation for a second order spring-mass system in terms of the wing panel geometry which yield the theoretical damping ratio and natural frequency of the wing.

REV

Theoretical Thrust

$$C_T = \frac{\sigma a}{2} (T_1 \lambda + T_2 \theta)$$

$$C_T = \frac{T}{\rho A V_T^2}$$

Forward

$$T = \frac{\sigma a \rho A V_T^2}{2} (T_1 \lambda + T_2 \theta)$$

$$\lambda = \frac{(V_0 \sin\alpha - v_F)}{V_T} \quad , \quad v = \frac{T}{2 \rho A V_0}$$

$$T = \frac{\sigma a \rho A V_T}{2} \left\{ \frac{\frac{T_1 V_0 \sin\alpha}{V_T} + T_2 \theta_0}{V_T^{-1} + \frac{\sigma a T_1}{4 V_0}} \right\}$$

Aft (Rear)

$$T = \frac{\sigma a \rho A V_T^2}{2} (T_1 \lambda + T_2 \theta)$$

$$\lambda = \frac{(V_0 \sin\alpha - v_R - d_F v_F)}{V_T}$$

$$T = \frac{\sigma a \rho A V_T}{2} \left\{ \frac{\frac{T_1 V_0 \sin\alpha}{V_T} - \frac{d_F T_F T_1}{2 \rho A V V_T} + T_2 \theta}{V_T^{-1} + \frac{\sigma a T_1}{4 V_0}} \right\}$$

Where

σ	Solidity Ratio
a	Slope Lift Coef. Curve vs. Rad.
ρ	Density
A	Area of Rotor (πR^2)
V_T	Velocity of Tip
T_1	Function of μ
T_2	Function of μ

REV

T	Thrust
V_o	Forward Velocity
θ	Collective Pitch
α	Angle of Attack of Shaft with Vertical Plane
v	Induced Velocity
d_f	Interference Factor f (γ s)
γ_s	Equals $i_\epsilon - \alpha + \tan^{-1} \dfrac{T_F}{2 q A}$
i_ϵ	The angle subtended by a line through the front and read hubs and X axis
q	Dynamic pressure (equals $1/2 \rho V^2_o$)

SUBSCRIPTS

F	Forward rotor
R	Rear rotor

REV

Collective Pitch

$$C_T = \frac{\sigma a}{2}(T_1 \lambda + T_2 \theta)$$

Let subscripts

a = no wing
b = with wing

Since thrust is constant

$$T_1 \lambda_a + T_2 \theta_a = T_1 \lambda_b + T_2 \theta_b$$

$$T_1 (\lambda_a - \lambda_b) = T_2 (\theta_b - \theta_a)$$

$$HP = \frac{T \lambda V_T}{550}$$

$$T_1 \left(\frac{T \lambda_a V_T}{550} - \frac{T \lambda_b V_T}{550} \right) = T_2 \left[\frac{T V_T}{550} \right] (\theta_b - \theta_a)$$

$$T_1 \Delta HP = T_2 \frac{T V_T}{550} \Delta \theta$$

$$\Delta HP = \frac{T_2}{T_1} \left[\frac{T V_T}{550} \right] \Delta \theta$$

$$= \frac{2}{3} \left[\frac{32 \times 534}{550 \times 57.3} \right] \Delta \theta$$

$$\Delta HP = .362 \Delta \theta$$

REV

FIGURE A

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

COLLECTIVE PITCH

NO WING VS. WITH WING

FORWARD ROTOR

ROTOR DISC LOADING 2.86#/FT^2

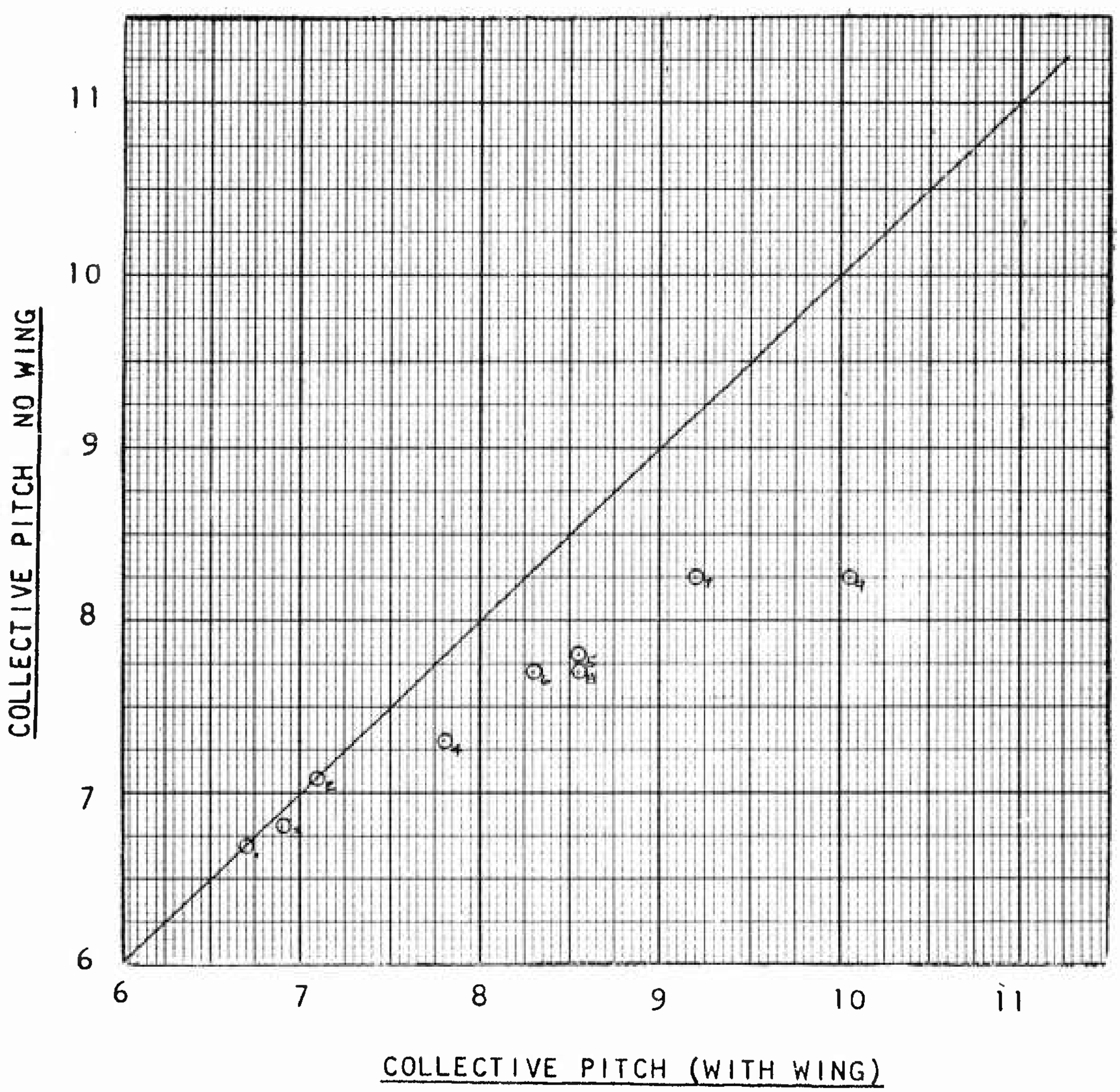


FIGURE 8

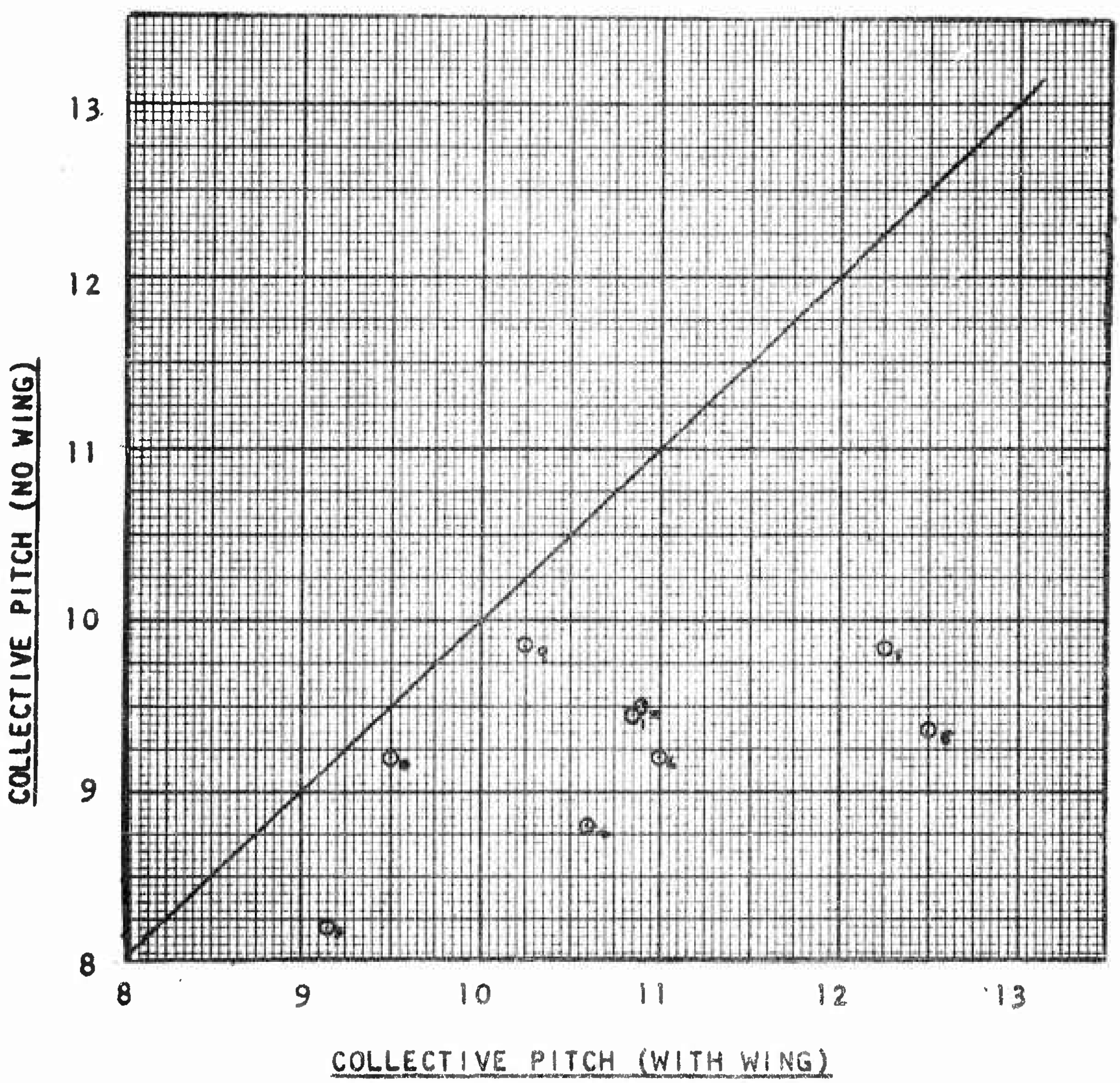
HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

COLLECTIVE PITCH

NO WING VS. WITH WING

REAR ROTOR

ROTOR DISC LOADING 2.86#/FT^2



WING PANEL FREQUENCY RESPONSE

The equation for second order spring-mass system is

$$I\ddot{\theta} + C\dot{\theta} + K\theta$$

In terms of the system's natural frequency and damping ratio

$$\ddot{\theta} + 2\zeta\omega_n\dot{\theta} + \omega_n^2\theta$$

Assuming the wing panel behaves as a second order system, the damping ratio and natural frequency of the panel can be calculated from the following expression

$$I\ddot{\theta} + C_{L_\alpha}\frac{qS\ell_1^2}{V_0}\dot{\theta} + C_L q S \ell_1 \sin\delta\,\theta$$

Scale Factor

Let $S.F. = \ell_m / \ell_{fs}$

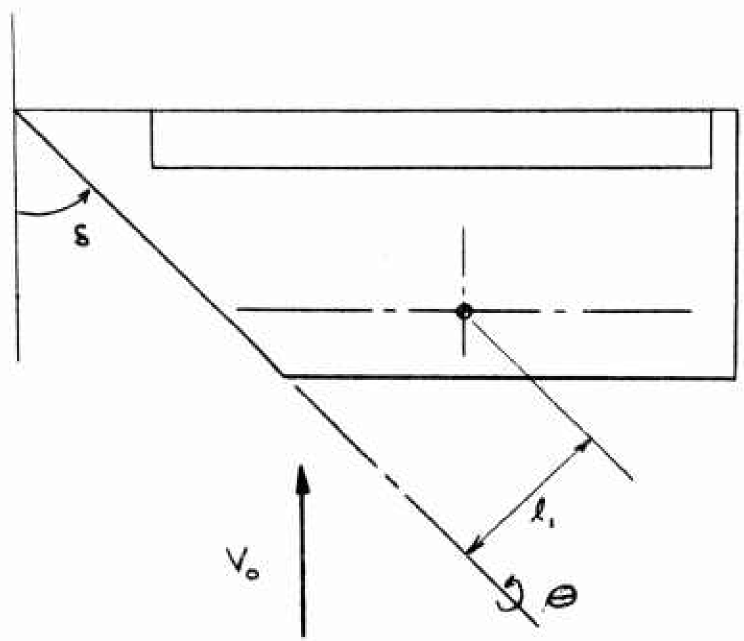
It can be shown that

$$\omega_{n_m} / \omega_{n_{fs}} = \sqrt{1/S.F.} = 3$$

$$\zeta_m / \zeta_{f.s.} = \sqrt{S.F.} = 1/3$$

REV

WING PANEL FREQUENCY RESPONSE



REV

APPENDIX C

The following appendix consists of tabulated data of the forces, moments, torque and resulting thrust and horsepower obtained from the tunnel balance system and model loads for the test points listed in the wind tunnel program (Appendix A).

REV

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

Summary of Total Lift, Drag, and Moment Coefficients

TUNNEL SPEED kts	COLLECTIVE PITCH FWD deg	COLLECTIVE PITCH AFT deg	ANGLE OF ATTACK deg	NO WING RUN NO.	NO WING $C_Z \times 10^4$	NO WING $C_X \times 10^4$	NO WING $C_M \times 10^4$	WOODEN WING RUN NO.	WOODEN WING $C_Z \times 10^4$	WOODEN WING $C_X \times 10^4$	WOODEN WING $C_M \times 10^4$	METAL WING RUN NO.	METAL WING $C_Z \times 10^4$	METAL WING $C_X \times 10^4$	METAL WING $C_M \times 10^4$
30	7	9	1	1	-33.52	-3.11	4.58	49	-37.26	-4.51	5.50				
30			-1					50	-36.33	-3.16	5.04				
30			-1	2	-33.52	-2.05	3.81	51	-36.33	-3.09	5.12				
40			1	3	-37.57	-3.83	5.17	52	-41.92	-4.96	6.65				
40			-1	4	-36.95	-2.54	4.09	53	-40.68	-3.62	5.67				
70			-5	5	-38.50	-2.94	1.53	54	-47.82	-5.05	7.34				
70			-8					55	-44.40	-2.93	6.71				
70			-8	6	-33.22	-1.11	.88	56	-43.47	-2.67	6.19				
70			-11					57	-36.95	-1.45	5.78				
70			-11	7	-27.01	-.07	.51	58	-36.33	-1.11	5.33				
80			-8	8	-32.60	-2.56	.41	59	-45.33	-4.31	7.23				
80			-11	9	-25.46	-1.65	-.12	60	-36.02	-2.77	5.33				
85			-9	10	-29.50	-2.94	0	61	-43.78	-4.92	7.52	114	-65.52	-8.86	14.86
85			-12					62	-34.47	-4.15	6.42	115	-56.20	-7.89	13.80
85			-12	11	-21.74	-2.31	-.47	63	-32.91	-3.67	5.72	116	-55.58	-8.79	13.34
85			-15					64	-22.98	-3.96	4.63	117	-44.40	-9.28	11.51
85			-15	12	-13.35	-2.97	.07	65	-19.87	-4.05	3.50	118	-44.09	-9.36	11.89
90			-12	13	-20.49	-3.20	-.56	66	-33.84	-4.50	5.81	119	-53.10	-9.73	12.78
90			-15	14	-10.87	-4.05	-.84	67	-30.74	-4.30	5.28	120	-42.85	-10.52	11.52
85			-9	15	-29.19	-3.00	.48	68	-43.78	-5.11	8.36				
85			-15	16	-12.42	-3.12	-.02	69	-21.42	-4.11	3.83				
85			-15	17	-12.11	-3.61	.20	70	-21.42	-4.64	4.18				
85	7	9	-9	18	-29.50	-3.53	.76	71	-43.16	-5.73	7.83				
30	10	9	1	19	-39.74	-4.12	11.45	72	-41.92	-5.12	11.45				
30			-1	20	-38.50	-2.59	10.52	73	-41.92	-3.97	10.95				
70			-5	21	-44.40	-3.27	9.09	74	-55.58	-5.56	14.86				
70			-8	22	-40.05	-1.24	8.37	75	-49.06	-2.68	13.07				
70			-11	23	-34.78	.55	8.43	76	-42.23	-.61	11.66				
85			-9	24	-38.19	-2.96	7.81	77	-50.61	-5.26	14.55	124	-70.17	-9.01	19.56
85			-12	25	-30.43	-1.57	7.74	78	-40.99	-3.22	12.61	125	-61.48	-8.35	18.44
85	10	9	-15	26	-21.74	-1.50	7.91	79	-29.50	-2.63	10.83	126	-50.92	-8.83	17.01
30	10	12	1	27	-49.37	-5.14	4.93	80	-48.75	-5.88	8.09				
30			-1					81	-47.20	-4.16	7.17				
30			-1	28	-49.37	-3.56	4.18	82	-47.20	-4.22	7.29				
40	10	12	1	29	-53.41	-5.69	5.61	83	-52.71	-6.35	8.63				

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

Summary of Total Lift, Drag, and Moment Coefficients

TUNNEL SPEED	COLLECTIVE PITCH		ANGLE OF ATTACK	NO WING				WOODEN WING				METAL WING			
kts	FWD deg	AFT deg	deg	RUN NO.	$C_Z \times 10^4$	$C_X \times 10^4$	$C_M \times 10^4$	RUN NO.	$C_Z \times 10^4$	$C_X \times 10^4$	$C_M \times 10^4$	RUN NO.	$C_Z \times 10^4$	$C_X \times 10^4$	$C_M \times 10^4$
40	10	12	-1	30	-53.41	-3.92	4.58	84	-51.85	-4.88	8.11				
70			-5	31	-55.58	-3.70	2.34	85	-62.41	-5.52	10.99				
70			-8					86	-57.13	-3.07	9.46				
70			-8	32	-52.47	-.89	1.47	87	-56.51	-2.50	9.17				
70			-11					88	-50.61	-.49	7.85				
70			-11	33	-47.20	-1.53	1.05	89	-49.06	-.16	7.46				
80			-8	34	-51.23	-2.48	1.26	90	-57.75	-4.19	9.58				
80			-11	35	-46.58	-.06	.59	91	-50.61	-1.84	7.86				
85			-9	36	-49.06	-2.64	.75	92	-59.0	-5.25	10.45	134	-81.35	-8.79	12.07
85			-12					93	-50.61	-3.21	9.32	135	-73.28	-6 38	9.73
85			-12	37	-44.09	-.39	.03	94	-48.75	-2.42	8.08	136	-73.28	-7.31	9.48
85			-15					95	-39.43	-1.44	6.84	137	-63.96	-5.96	7.55
85			-15	38	-35.09	-.92	-.25	96	-37.88	-1.16	5.80	138	-63.65	-6.04	7.58
90			-12	39	-42.54	-1.26	.03	97	-48.75	-3.33	8.28	139	-72.35	-8.43	9.10
90	10	12	-15	40	-35.09	-.04	-.66	98	-36.33	-2.19	5.92	140	-62.10	-7.02	7.21
30	7	12	1	41	-43.78	-4.39	-.28	99	-43.47	-5.18	2.21				
30			-1	42	-43.78	-2.84	-1.98	100	-42.54	-3.76	1.68				
70			-5	43	-48.44	-3.23	-3.89	101	-54.96	-8.68	3.33				
70			-8	44	-43.47	-.84	-5.35	102	-49.37	-2.49	2.48				
70			-11	45	-37.88	.93	-6.26	103	-41.61	-.48	.74				
85			-9	46	-40.88	-2.67	-6.09	104	-50.92	-4.86	3.70	144	-75.76	-8.34	8.10
85			-12	47	-33.84	-1.09	-7.38	105	-39.74	-2.81	1.00	145	-66.76	-6.73	5.25
85	7	12	-15	48	-26.39	-.71	-8.60	106	-27.63	-2.55	-1.52	146	-57.13	-7.21	3.01

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

Summary of Vertical Tunnel Force and Total Rotor Thrust

$Z = 1.61\ (C_Z)$ Tunnel Data
T_A = Aft Thrust
T_F = Fwd Thrust

TUNNEL SPEED	COLLECTIVE PITCH FWD	COLLECTIVE PITCH AFT	ANGLE OF ATTACK	NO WING RUN NO.	NO WING Z	NO WING $T_F + T_A$	WOODEN WING RUN NO.	WOODEN WING Z	WOODEN WING $T_F + T_A$	METAL WING RUN NO.	METAL WING Z	METAL WING $T_F + T_A$
kts	deg	deg	deg		lbs	lbs		lbs	lbs		lbs	lbs
30	7	9	1	1	-53.98	53.6	49	-59.99	53.6			
30			-1				50	-58.49	52.			
30			-1	2	-53.98	50.2	51	-58.33	51.			
40			1	3	-60.49	58.0	52	-67.49	59.6			
40			-1	4	-59.49	56.6	53	-65.49	56.6			
70			-5	5	-61.98	60.7	54	-76.99	56.2			
70			-8				55	-71.48	48.1			
70			-8	6	-53.45	51.2	56	-69.98	48.1			
70			-11				57	-59.48	42.1			
70			-11	7	-43.49	41.7	58	-58.49	40.1			
80			-8	8	-52.48	49.5	59	-72.98	46.7			
80			-11	9	-40.99	39.0	60	-57.99	35.7			
85			-9	10	-47.49	46.2	61	-70.49	41.4	114	-105.5	35.6
85			-12				62	-55.49	36.2	115	-90.5	29.8
85			-12	11	-35.00	33.5	63	-52.99	29.9	116	-89.5	29.8
85			-15				64	-37.0	16.7	117	-71.5	24.0
85			-15	12	-21.49	18.9	65	-31.99	16.2	118	-71.0	16.0
90			-12	13	-32.98	30.8	66	-54.48	26.8	119	-85.5	26.6
90			-15	14	-17.50	16.0	67	-49.5	26.8	120	-69.0	13.7
85			-9	15	-46.99	46.9	68	-70.5	41.2			
85			-15	16	-19.99	19.2	69	-34.5	16.7			
85			-15	17	-19.49	19.3	70	-34.5	17.1			
85	7	9	-9	18	-47.49	46.9	71	-69.5	41.7			

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

Summary of Vertical Tunnel Force and Total Rotor Thrust

Ƶ = 1.61 ($C_Ƶ$) Tunnel Data
T_A = Aft Thrust
T_F = Fwd Thrust

TUNNEL SPEED	COLLECTIVE PITCH FWD	COLLECTIVE PITCH AFT	ANGLE OF ATTACK	NO WING RUN NO.	NO WING Ƶ	NO WING $T_F + T_A$	WOODEN WING RUN NO.	WOODEN WING Ƶ	WOODEN WING $T_F + T_A$	METAL WING RUN NO.	METAL WING Ƶ	METAL WING $T_F + T_A$
kts	deg	deg	deg		lbs	lbs		lbs	lbs		lbs	lbs
30	10	9	1	19	-63.98	68.7	72	-67.5	60.6			
30			-1	20	-61.98	66.1	73	-67.5	59.1			
70			-5	21	-71.48	76.65	74	-89.5	64.6			
70			-8	22	-64.48	68.6	75	-79.	57.1			
70			-11	23	-55.99	60.4	76	-68.	49.6			
85			-9	24	-61.48	64.7	77	-81.5	53.7	124	-113	50.9
85			-12	25	-48.99	52.6	78	-66.0	41.2	125	-99	38.2
85	10	9	-15	26	-35.00	39.6	79	-48.5	31.0	126	-82	26.9
30	10	12	1	27	-79.48	82.9	80	-78.5	69.0			
30			-1				81	-76.0	79.1			
30			-1	28	79.5	81.	82	76.	66.1			
40			1	29	86.	90.7	83	85.	74.1			
40			-1	30	86.	89.2	84	83.5	74.6			
70			-5	31	89.5	92.2	85	100.5	75.1			
70			-8				86	92.	67.2			
70			-8	32	84.5	87.2	87	91.	67.2			
70			-11				88	81.5	50.1			
70			-11	33	76.0	79.1	89	79.	60.1			
80			-8	34	82.5	84.6	90	93.	67.2			
80			-11	35	75.0	77.2	91	81.5	57.7			
85			-9	36	79.0	81.7	92	95.	64.3	134	131	68.9
85			-12				93	81.5	53.7	135	118	58.6
85	10	12	-12	37	71.0	73.2	94	78.5	53.2	136	118	58.6

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

Summary of Vertical Tunnel Force and Total Rotor Thrust

$Z = 1.61\ (C_Z)$ Tunnel Data
T_A = Aft Thrust
T_F = Fwd Thrust

TUNNEL SPEED kts	COLLECTIVE PITCH FWD deg	COLLECTIVE PITCH AFT deg	ANGLE OF ATTACK deg	NO WING RUN NO.	NO WING Z lbs	NO WING $T_F + T_A$ lbs	WOODEN WING RUN NO.	WOODEN WING Z lbs	WOODEN WING $T_F + T_A$ lbs	METAL WING RUN NO.	METAL WING Z lbs	METAL WING $T_F + T_A$ lbs
85	10	12	-15				95	63.5	47.2	137	103	56.1
85	↕	↕	-15	38	56.5	61.1	96	61.0	41.2	138	103	48.0
90	↕	↕	-12	39	68.5	71.7	97	78.5	51.2	139	116.5	58.0
90	10	12	-15	40	56.5	59.6	98	58.5	39.1	140	100	45.4
30	7	12	1	41	70.5	66.7	99	70.0	61.6			
30	↕	↕	-1	42	70.5	66.	100	68.5	60.0			
70	↕	↕	-5	43	78.0	74.7	101	88.5	65.7			
70	↕	↕	-8	44	70.0	67.7	102	79.5	57.2			
70	↕	↕	-11	45	61.0	57.4	103	67.0	47.6			
85	↕	↕	-9	46	65.5	61.2	104	82.0	52.7	144	122	59.5
85	↕	↕	-12	47	54.5	51.7	105	64.0	40.2	145	107.5	49.4
85	7	12	-15	48	42.5	39.5	106	43.5	27.0	146	92.0	36.7

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

Summary of Rotor Thrust and Rotor Horsepower

TUNNEL SPEED kts	COLLECTIVE PITCH FWD deg	COLLECTIVE PITCH AFT deg	ANGLE OF ATTACK deg	NO WING RUN NO.	NO WING THRUST FWD lbs	NO WING THRUST AFT lbs	NO WING HORSEPOWER FWD	NO WING HORSEPOWER AFT	WOODEN WING RUN NO.	WOODEN WING THRUST FWD lbs	WOODEN WING THRUST AFT lbs	WOODEN WING HORSEPOWER FWD	WOODEN WING HORSEPOWER AFT	METAL WING RUN NO.	METAL WING THRUST FWD lbs	METAL WING THRUST AFT lbs	METAL WING HORSEPOWER FWD	METAL WING HORSEPOWER AFT
30	7	9	1	1	33.6	20.0	1.65	1.5	49	32.6	21.0	1.65	1.4					
30			-1	2	29.2	21.0	1.65	1.5	51	30.0	21.0	1.70	1.2					
40			1	3	35	23	1.55	1.5										
40			-1	4	33.6	23	1.65	1.55										
70			-5	5	32.6	28.1	1.65	1.65	54	31.1	25.1	1.65	1.50					
70			-8	6	27.1	24.1	1.80	1.70	56	26.1	22.0	1.70	1.45					
70			-11	7	21.7	20.0	1.85	1.40	58	22.1	18.0	1.80	1.45					
80			-8	8	25.3	24.2	1.80	1.50										
80			-11	9	20.0	19.0	1.85	1.45										
85			-9	10	23.6	22.6	1.83	1.50	61	22.2	19.2	1.70	1.45	114	23	18.4	1.73	1.45
85			-12	11	17.0	16.5	1.83	1.50	63	14.6	15.1	1.70	1.20	116	17.3	12.6	1.73	1.12
85			-15	12	9.7	9.2	1.60	1.00	65	9.1	7.1	1.50	.80	118	9.8	6.3	1.54	.24
90			-12	13	15.4	15.4	1.80	1.40										
90			-15	14	8.5	7.5	1.55	1.10										
35			-9	15	24.3	22.6	1.83	1.55	68	22.1	19.1	1.75	1.30					
85			-15	16	10.2	9.0	1.60	1.20	69	9.6	7.1	1.50	.95					
85			-15	17	10.3	9.0	1.60	1.20	70	10.0	7.1	1.55	.95					
85	7	9	-9	18	24.3	22.6	1.85	1.70	71	22.6	19.1	1.80	1.15					
30	10	9	1	19	52.8	15.9	2.85	1.40	72	43.6	17.0	2.65	1.0					
30			-1	20	50.1	16.0	2.90	1.40	73	42.1	17.0	2.70	.8					
70			-5	21	53.4	23.3	2.75	1.60	74	43.6	21.0	2.55	1.05					
70			-8	22	48.6	20.0	2.80	1.50	75	39.1	18.0	2.55	.8					
70			-11	23	44.4	16.0	2.80	1.45	76	35.1	14.5	2.60	.8					
85			-9	24	45.6	19.1	2.75	1.45	77	37.2	16.1	2.55	1.0	124	34.6	16.5	2.2	1.07
85			-12	25	40.6	12.0	2.80	1.20	78	31.1	10.1	2.60	.6	125	28.0	10.2	2.28	.83
85	10	9	-15	26	34.1	5.5	2.80	1.18	79	26.1	4.5	2.60	.4	126	22.1	4.8	2.31	.47
30	10	12	1	27	52.1	30.9	2.80	2.55	80	44.1	25.0	2.65	1.6					
30			-1	28	49.5	31.5	2.80	2.55	82	41.1	25.0	2.65	1.5					
40			1	29	56.6	34.1	2.75	2.55										
40			-1	30	55.1	34.2	2.75	2.40										
70			-5	31	53.1	39.1	2.75	2.35	85	44.5	30.6	2.55	1.7					
70			-8	32	49.1	38.1	2.75	2.45	87	39.1	28.1	2.60	1.5					
70			-11	33	45.1	34.1	2.75	2.40	89	35.1	25.0	2.60	1.35					
80	10	12	-8	34	47.3	37.3	2.75	2.25										

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

Summary of Rotor Thrust and Rotor Horsepower

TUNNEL SPEED kts	COLLECTIVE PITCH FWD deg	COLLECTIVE PITCH AFT deg	ANGLE OF ATTACK deg	NO WING RUN NO.	NO WING THRUST FWD lbs	NO WING THRUST AFT lbs	NO WING HORSEPOWER FWD	NO WING HORSEPOWER AFT	WOODEN WING RUN NO.	WOODEN WING THRUST FWD lbs	WOODEN WING THRUST AFT lbs	WOODEN WING HORSEPOWER FWD	WOODEN WING HORSEPOWER AFT	METAL WING RUN NO.	METAL WING THRUST FWD lbs	METAL WING THRUST AFT lbs	METAL WING HORSEPOWER FWD	METAL WING HORSEPOWER AFT
80	10	12	-11	35	43.1	34.1	2.75	2.30										
85			-9	36	46.1	35.6	2.75	2.35	92	37.2	27.1	2.55	1.8	134	33.7	35.2	2.23	2.34
85			-12	37	41.1	32.1	2.75	2.25	94	31.1	22.1	2.55	1.7	136	27.2	31.4	2.31	2.07
85			-15	38	35.0	26.1	2.75	2.35	96	24.6	16.6	2.60	1.5	138	22.2	25.8	2.27	1.88
90			-12	39	40.6	31.1	2.70	2.40										
90	10	12	-15	40	34.0	25.6	2.70	2.35										
30	7	12	1	41	31.7	35	1.65	2.65	99	32.5	29.1	1.65	1.55					
30			-1	42	30.5	35.5	1.70	2.65	100	31.0	29.0	1.70	1.45					
70			-5	43	32.1	42.6	1.65	2.60	101	30.6	35.1	1.65	1.55					
70			-8	44	27.0	40.7	1.80	2.70	102	26.1	31.1	1.70	1.70					
70			-11	45	20.2	37.2	1.85	2.50	103	20.5	27.1	1.70	1.80					
85			-9	46	23.0	38.2	1.80	2.35	104	23.1	29.6	1.70	1.95	144	22.6	36.9	1.67	1.81
85			-12	47	17.0	34.7	1.80	2.25	105	16.1	24.1	1.65	1.85	145	16.4	33.0	1.63	1.77
85	7	12	-15	48	10.0	29.5	1.60	2.25	106	9.0	18.0	1.50	1.70	146	9.4	27.3	1.40	1.59

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

Summary of Rotor Shaft Power & Motor Power

TUNNEL SPEED kts	COLLECTIVE PITCH FWD deg	COLLECTIVE PITCH AFT deg	ANGLE OF ATTACK deg	NO WING RUN NO.	NO WING HP FWD	NO WING HP AFT	NO WING HP TOTAL	NO WING HP MOTOR	NO WING EFF. TOTAL MOTOR	NO WING Δ HP MOTOR -TOTAL	WOODEN WING RUN NO.	WOODEN WING HP FWD	WOODEN WING HP AFT	WOODEN WING HP TOTAL	WOODEN WING HP MOTOR	WOODEN WING EFF. TOTAL MOTOR	WOODEN WING Δ HP MOTOR -TOTAL	METAL WING RUN NO.	METAL WING HP FWD	METAL WING HP AFT	METAL WING HP TOTAL	METAL WING HP MOTOR	METAL WING EFF. TOTAL MOTOR	METAL WING Δ HP MOTOR -TOTAL
30	7	9	1	1	1.65	1.50	3.15	3.67	.86	.52	49	1.65	1.4	3.05	3.78	.81	.73							
30			-1								50													
30			-1	2	1.65	1.50	3.15	3.73	.84	.58	51	1.70	1.2	2.90	3.78	.77	.88							
40			1	3	1.55	1.50	3.05	3.57	.85	.52	52													
40			-1	4	1.65	1.55	3.20	3.67	.87	.47	53													
70			-5	5	1.65	1.65	3.30	3.78	.87	.48	54	1.65	1.50	3.15	3.78	.83	.63							
70			-8								55													
70			-8	6	1.80	1.70	3.50	3.89	.90	.39	56	1.70	1.45	3.15	3.89	.81	.74							
70			-11								57													
70			-11	7	1.85	1.40	3.25	3.89	.84	.64	58	1.80	1.45	3.25	3.89	.84	.64							
80			-8	8	1.80	1.50	3.30	3.78	.87	.48	59													
80			-11	9	1.85	1.45	3.30	3.78	.87	.48	60													
85			-9	10	1.83	1.50	3.33	3.78	.88	.45	61	1.70	1.45	3.15	3.89	.81	.74	114	1.73	1.45	3.18	3.68	.87	.48
85			-12								62							115						
85			-12	11	1.83	1.50	3.33	3.68	.90	.35	63	1.70	1.20	2.90	3.57	.81	.67	116	1.73	1.12	2.85	3.57	.80	.72
85			-15								64							117						
85			-15	12	1.60	1.00	2.60	3.13	.83	.53	65	1.50	.80	2.30	3.02	.76	.72	118	1.54	.24	1.78	2.92	.62	1.12
90			-12	13	1.80	1.40	3.20	3.57	.90	.37	66							119						
90			-15	14	1.55	1.10	2.65	2.97	.89	.32	67							120						
85			-9	15	1.83	1.55	3.38	3.78	.89	.40	68	1.75	1.30	3.05	3.78	.81	.73							
85			-15	16	1.60	1.20	2.80	3.13	.89	.33	69	1.50	.95	2.45	3.02	.81	.57							
85			-15	17	1.60	1.20	2.80	3.13	.89	.33	70	1.55	.95	2.50	3.02	.83	.52							
85	7	9	-9	18	1.85	1.70	3.55	3.89	.91	.34	71	1.80	1.15	2.95	3.78	.78	.83							
30	10	9	1	19	2.85	1.40	4.25	4.65	.91	.40	72	2.65	1.0	3.65	4.59	.80	.94							
30			-1	20	2.90	1.40	4.30	4.65	.92	.35	73	2.70	.8	3.50	4.65	.75	1.15							
70			-5	21	2.75	1.60	4.35	5.30	.82	.95	74	2.55	1.05	3.60	4.59	.78	.99							
70			-8	22	2.80	1.50	4.30	5.30	.81	1.00	75	2.55	.8	3.35	4.65	.72	1.30							
70			-11	23	2.80	1.45	4.25	5.30	.80	1.05	76	2.60	.8	3.40	4.65	.73	1.25							
85			-9	24	2.75	1.45	4.20	5.30	.79	1.10	77	2.55	1.0	3.55	4.54	.78	.99	124	2.2	1.07	3.27	4.22	.78	.92
85			-12	25	2.80	1.20	4.00	4.60	.87	.60	78	2.60	.6	3.20	4.43	.72	1.23	125	2.28	.83	3.11	3.57	.87	.46
85	10	9	-15	26	2.80	1.20	4.00	4.11	.98	.11	79	2.60	.4	3.00	4.22	.71	1.22	126	2.31	.47	2.78	3.68	.76	.88
30	10	12	1	27	2.80	2.55	5.35	6.05	.88	.70	80	2.65	1.6	4.25	5.2	.81	.95							
30			-1								81													
30	10	12	-1	28	2.80	2.55	5.35	6.11	.88	.76	82	2.65	1.5	4.15	5.3	.78	1.15							
40			1	29	2.75	2.55	5.30	5.95	.89	.65	83													
40			-1	30	2.75	2.40	5.15	6.05	.85	.90	84													
70			-5	31	2.75	2.35	5.10	5.95	.86	.85	85	2.55	1.7	4.25	5.3	.80	1.05							
70			-8								86													
70			-8	32	2.75	2.45	5.20	6.05	.86	.85	87	2.60	1.5	4.10	5.3	.77	1.20							
70			-11								88													
70			-11	33	2.75	2.40	5.15	6.05	.85	.90	89	2.60	1.35	3.95	5.3	.75	1.35							
80			-8	34	2.75	2.25	5.00	6.05	.83	1.05	90													
80			-11	35	2.75	2.30	5.05	6.05	.83	1.00	91													
85			-9	36	2.75	2.35	5.10	6.05	.84	.95	92	2.55	1.8	4.35	5.20	.84	.85	134	2.23	2.34	4.57	5.41	.84	.84
85			-12								93													
85			-12	37	2.75	2.25	5.00	6.05	.83	1.05	94	2.55	1.7	4.25	5.20	.82	.95	136	2.31	2.07	4.38	5.51	.80	1.13
85			-15								95													
85			-15	38	2.75	2.35	5.10	6.05	.84	.95	96	2.60	1.5	4.10	5.10	.80	1.00	138	2.27	1.88	4.15	5.41	.77	1.26
90			-12	39	2.70	2.40	5.10	6.05	.84	.95	97													
90	10	12	-15	40	2.70	2.35	5.05	6.05	.83	1.00	98													

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

Summary of Rotor Shaft Power & Motor Power

TUNNEL SPEED kts	COLLECTIVE PITCH FWD deg	COLLECTIVE PITCH AFT deg	ANGLE OF ATTACK deg	NO WING RUN NO.	NO WING HP FWD	NO WING HP AFT	NO WING HP TOTAL	NO WING HP MOTOR	NO WING EFF. TOTAL MOTOR	NO WING Δ HP MOTOR -TOTAL	WOODEN WING RUN NO.	WOODEN WING HP FWD	WOODEN WING HP AFT	WOODEN WING HP TOTAL	WOODEN WING HP MOTOR	WOODEN WING EFF. TOTAL MOTOR	WOODEN WING Δ HP MOTOR -TOTAL	METAL WING RUN NO.	METAL WING HP FWD	METAL WING HP AFT	METAL WING HP TOTAL	METAL WING HP MOTOR	METAL WING EFF. TOTAL MOTOR	METAL WING Δ HP MOTOR -TOTAL
30	7	12	1	41	1.65	2.65	4.30	4.86	.88	.56	99	1.65	1.55	3.20	4.32	.74	1.12							
30			-1	42	1.70	2.65	4.35	5.08	.86	.73	100	1.70	1.45	3.15	4.32	.73	1.17							
70			-5	43	1.65	2.60	4.25	4.86	.87	.61	101	1.65	1.55	3.20	4.21	.76	1.01							
70			-8	44	1.80	2.70	4.50	5.08	.88	.58	102	1.70	1.70	3.40	4.32	.79	.92							
70			-11	45	1.85	2.50	4.15	4.86	.85	.71	103	1.70	1.80	3.50	4.43	.79	.93							
85			-9	46	1.80	2.35	4.15	4.86	.85	.71	104	1.70	1.95	3.65	4.32	.84	.67	144	1.67	1.81	3.48	4.97	.70	1.49
85			-12	47	1.80	2.25	4.15	4.86	.85	.71	105	1.65	1.85	3.50	4.32	.81	.82	145	1.63	1.77	3.40	4.97	.68	1.57
85	7	12	-15	48	1.60	2.25	3.95	4.65	.85	.70	106	1.50	1.70	3.20	4.00	.80	.80	146	1.40	1.59	2.99	4.65	.65	1.66

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

Comparison of Data in and out of Ground Effect

CONFIGURATION	TUNNEL SPEED	COLLECTIVE PITCH FWD deg	COLLECTIVE PITCH AFT deg	ANGLE OF ATTACK deg	RUN NO.	$C_Z \times 10^4$	$C_X \times 10^4$	$C_M \times 10^4$	THRUST FWD lbs	THRUST AFT lbs	HP FWD	HP AFT	HP TOTAL
NO WING	30	7	9	1	152 / 1	-48.13 / -33.53	-3.83 / -3.11	1.43 / 4.58	41.8 / 33.6	35.1 / 20.0	2.12 / 1.65	2.09 / 1.5	4.21 / 3.15
	30	7	9	-1	153 / 2	-38.13 / -33.53	-2.06 / -2.05	.47 / 3.81	39.4 / 29.2	35.5 / 21.0	2.16 / 1.65	1.80 / 1.5	3.96 / 3.15
	70	7	9	-5	154 / 5	-52.17 / -38.5	-3.77 / -2.93	-.65 / 1.53	41.0 / 32.6	41.4 / 28.1	2.02 / 1.65	1.29 / 1.65	3.31 / 3.30
	70	7	9	-8	155 / 6	-47.51 / -33.22	-1.18 / -1.11	-1.76 / .88	35.4 / 27.1	39.5 / 24.1	1.36 / 1.80	1.45 / 1.70	3.01 / 3.50
	70	7	9	-11	156 / 7	-42.85 / -27.01	.85 / -.07	-2.75 / .51	30.4 / 21.7	44.1 / 20.0	1.44 / 1.85	1.10 / 1.40	2.54 / 3.25
WOODEN WING	30	7	9	1	157 / 49	-51.85 / -37.26	-4.59 / -4.51	3.02 / 5.50	41.8 / 32.6	36.4 / 21.0	2.20 / 1.65	.95 / 1.4	3.15 / 3.05
	30	7	9	-1	158 / 51	-51.85 / -36.33	-3.04 / -3.09	1.80 / 5.12	38.9 / 30.0	38.3 / 21.0	2.24 / 1.70	.67 / 1.2	2.91 / 2.90
METAL WING	85	7	9	-9	159 / 114	-84.77 / -65.52	-7.73 / -8.86	11.78 / 14.86	35.4 / 23	38.0 / 18.4	2.08 / 1.73	2.52 / 1.45	4.60 / 3.18
	85	7	9	-12	160 / 116	-75.45 / -55.58	-6.12 / -8.79	9.10 / 13.34	27.6 / 17.3	33.3 / 12.6	2.20 / 1.73	2.71 / 1.12	4.91 / 2.85
	85	7	9	-15	161 / 118	-65.52 / -44.09	-5.22 / -9.36	7.03 / 11.89	21.3 / 9.8	27.8 / 6.3	2.20 / 1.54	1.62 / .24	3.82 / 1.78

APPENDIX D

UNIVERSITY OF MARYLAND
WIND TUNNEL REPORT NO. 278

WIND TUNNEL TEST OF A
HELICOPTER RANGE EXTENSION MODEL

REV

TABLE OF CONTENTS

REV

SUMMARY

Wind tunnel tests were conducted on a one-ninth scale helicopter model at the University of Maryland Wind Tunnel for the Vertol Aircraft Corporation. These tests were conducted to investigate the feasibility of using floating wing fuel tanks to extend the present range of the helicopter.

This report presents the six component balance data from the wind tunnel tests and explains how they were obtained.

REV

INTRODUCTION

Wind tunnel tests were conducted on a one-ninth scale helicopter model for Vertol Aircraft Corporation at the University of Maryland Wind Tunnel during the period of March 14, 1960 through March 23, 1960. Messrs. C. B. Fay, M. J. Drozda, G. Besser and J. W. Mayer represented Vertol Division of Boeing Airplane Company and witnessed the tests.

The purpose of the test was to investigate the feasibility of using floating wing fuel tanks to extend the present helicopter range. Runs were made to determine changes in stability characteristics of the helicopter with wing fuel tanks, effect on induced power, on front and rear rotor, due to presence of the wing and stability characteristics of the floating wing fuel tank in and out of ground effect. At the end of the test the wing panels were jettisoned to determine their trajectory relative to the helicopter model.

REV

DESCRIPTION OF THE MODEL

A one-ninth scale powered model of the HUP helicopter was used for the wind tunnel tests. This model was originally built by the U. S. Navy David Taylor Model Basin. It was modified by the Vertol Aircraft Corporation. In addition to the basic HUP fuselage, the Vertol modification could be equipped with steel wing stubs which would accommodate instrumented wood wing or metal wing panels. The panels were instrumented to record wing attitude and wing flap position.

The tandem model rotors were driven by a thirty horsepower induction motor. The rotor heads were equipped with strain gages to measure the lift, drag, torque and pitching moment of the rotors.

Dummy wood and metal wing panels were used for the jettison test. The metal wing simulated the full fuel load in the wing whereas the wood wing simulated the empty condition.

An angle of attack drive mechanism was incorporated within the model fuselage. This made it possible to pitch and yaw the model at the same time on a single support mount.

REV

TEST PROCEDURE

The helicopter model was mounted in the 7.75 by 11 foot test section of the wind tunnel on a single support system as shown in Figure 1. Indicated air speed varied from 30 knots to 90 knots during the test program. The tunnel speeds and corresponding dynamic pressures used during the test are presented in the Vertol test program (Pages 19-21). Tunnel speed was adjusted to account for the blockage of the single support fairing.

The rotor tip speed was maintained at a constant velocity of 534 feet per second throughout the test. This speed was held constant speed of 5694 rpm. Input power and speed of the model motor was monitored continuously during the test.

Testing was broken down into several phases. In the first portion, power and stability information were obtained for the helicopter alone. In the second phase, metal and wood wings were tested on the helicopter. Low wing loading power and stability information were obtained with the wood wing whereas the metal wing was used to obtain high wing loading data. Several runs were made with a ground board installed in the test section to obtain ground proximity effects. The last phase of the test was the wing panel jettison runs. These runs were made to determine the trajectory of the wing panel relative to the model.

A wind tunnel test program is presented on Pages 17 and 18. In addition to the wind tunnel record a Vertol Division of Boeing Airplane Company wind tunnel program is included in this report on Pages 19-21. The reason both records appear is that for the tunnel records it is easier to consider a run as from the time the tunnel is started until the time it is stopped, during which period many Vertol runs could be completed. A column has been included in the wind tunnel test program to correlate the two programs.

REV

Six component force and moment data of the complete model were recorded during the test. These data were obtained from the wind tunnel balance system. In addition to these readings, drag, lift, torque and pitching moment data were obtained for the rotor heads from strain gages mounted in the model.

For that portion of the test where the wing panels were installed on the model, wing attitude and flap position were recorded. It will be noted from the wind tunnel test program that all Vertol runs were not made. Only runs with a tunnel speed of 85 knots or higher were made when the metal wing was installed on the model.

Photographic records were taken of the wing panel drop tests and wing dynamics studies.

REV

PRESENTATION OF DATA

The results of the wind tunnel balance readings are presented in nondimensional form as defined on page 15. The following constants were used in the data reduction:

V_T = rotor tip speed = 534 ft./sec.

R = rotor radius = 1.944 ft.

$\rho\, 2\pi R^2 V_T^2 = 16,108$ lb.

$\rho\, 2\pi R^3 V_T^2 = 31,322$ ft. lb.

Standard wall corrections used for normal wind tunnel tests were applied to the data. These corrections are as follows:

$$\Delta\alpha_{TW} = \delta \frac{S}{C} C_L \times 57.3$$

$$\Delta C_{D_{TW}} = \delta \frac{S}{C} C_L^2$$

In the above equations δ is the wall correction factor and is a function of the type and geometry of the tunnel test section, location of the vortex system in the test section, and the spanwise load distribution. The value of δ was obtained from Reference 1 for a vortex span equal to the rotor diameter. S, which is normally the wing area, was taken to be the swept area of the rotor disks and C is the cross sectional area of the test section. C_L is the lift coefficient as defined on page 15, not to be confused with C_Z as used in this report. The tunnel wall corrections are presented in Table I in terms of C_Z.

With the ground board installed, the tunnel wall corrections change and are as follows:

$$\Delta\alpha_{TW} = \delta \frac{S}{N C_G} C_L \times 57.3$$

$$\Delta C_{D_{TW}} = \delta \frac{S}{N C_G} C_L^2$$

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Here δ_N is the tunnel wall correction factor with the ground board installed and C_G is the area of the ground board test section. The tunnel wall corrections for the ground board installed are presented in Table II in terms of C_Z.

All data are presented for wind axes through the model C.G. The following equations were used to transfer the data from the wind axes through the balance center to the wind axes through the model CG.

$$C_{M_{CG}} = C_{M_{BC}} - C_Z \left(\frac{h}{R}\right) \sin\alpha \cos\psi + C_X \left(\frac{h \cos\alpha - y}{R}\right)$$

$$C_{N_{CG}} = C_{N_{BC}} + C_Y \left(\frac{h}{R}\right) \sin\alpha \cos\psi - C_X \left(\frac{h}{R}\right) \sin\alpha \sin\psi$$

$$C_{\mathcal{L}_{CG}} = C_{\mathcal{L}_{BC}} - C_Y \left(\frac{h \cos\alpha - y}{R}\right) + C_Z \left(\frac{h}{R}\right) \sin\alpha \sin\psi$$

Where: subscript CG indicates model center of gravity

subscript BC indicates balance center

h = distance from model CG to balance center

= 0.4233 ft.

y = balance center to pivot point distance

= 0.0358

R = rotor radius

Tabulated data are presented on pages 23-38.

The input power to the model motor for the test runs is also presented on the tabulated data sheets.

All strain gage data were recorded by the Vertol Aircraft Corporation representatives and do not appear in this report.

Wing jettison tests were recorded with motion picture cameras. A Fastax camera was used to take high speed pictures (1,000 frames per second) from the side. At the same time pictures were taken with a camera mounted downstream of the model at 64 frames per second.

REV

REMARKS

The method used to correct the data for tunnel wall effects was based upon the information presented in Reference 2.

REV

REFERENCES

1. Sekscienski, W. S., Information for Users of the Glenn L. Martin Institute of Technology Low Speed Wind Tunnel; Part3, Data Reduction Procedures, University of Maryland Wind Tunnel.

2. Rae, W. H., and Ganzer, V. M., An Experimental Investigation of the Effect of Wind Tunnel Walls on a Lifting Rotor in a Closed Rectangular Test Section, University of Washington.

REV

TABLE I

Tunnel Wall Corrections

δ = 0.116

C = 84.88 sq. ft.

S = 23.756 sq. ft.

Tunnel Speed V Knots	q lbs/sq. ft.	$\Delta \alpha_{TW}$	$\Delta C_{X_{TW}}$
30	3.05	$-413.580\ C_Z$	$-7.2178\ C_Z^2$
40	5.43	$-232.018\ C_Z$	$-4.0542\ C_Z^2$
70	16.6	$-75.989\ C_Z$	$-1.3262\ C_Z^2$
80	21.7	$-58.130\ C_Z$	$-1.0145\ C_Z^2$
85	24.6	$-51.277\ C_Z$	$-0.8949\ C_Z^2$
90	27.5	$-45.870\ C_Z$	$-0.8005\ C_Z^2$

REV

TABLE II

Tunnel Wall Corrections for
Ground Board Test Section

$\delta_N = 0.0122$

$C_G = 46.260$ Sq. Ft.

$S = 23.756$ Sq. Ft.

Tunnel Speed V Knots	q lbs/sq. ft.	$\Delta\alpha_{TW}$	$AC_{X_{TW}}$
30	3.05	$-79.661\ C_Z$	$-1.3902\ C_Z^2$
70	16.6	$-14.636\ C_Z$	$-.2554\ C_Z^2$
85	24.6	$-9.877\ C_Z$	$-.1724\ C_Z^2$

REV

TABLE III

Rotor Collective Pitch

No.	Front Rotor	Rear Rotor
1	7°	9°
2	10°	9°
3	10°	12°
4	7°	12°

REV

SYMBOLS

Forces and Moments (see sketch)

X Force and X direction, lbs.

Y Force and Y direction, lbs.

Z Force and Z direction, lbs.

$\mathcal{L}$ Rolling moment, ft. lbs.

M Pitching moment, ft. lbs.

N Yawing moment, ft. lbs.

L Lift, lbs., = -Z.

D Drag, lbs., = -X.

Nondimensional Forces and Moments

$$C_X = \frac{X}{\rho 2\pi R^2 V_T^2}$$

$$C_Y = \frac{Y}{\rho 2\pi R^2 V_T^2}$$

$$C_Z = \frac{Z}{\rho 2\pi R^2 V_T^2}$$

$$C_{\mathcal{L}} = \frac{\mathcal{L}}{2\pi R^3 V_T^2}$$

$$C_M = \frac{M}{\rho 2\pi R^3 V_T^2}$$

$$C_N = \frac{N}{\rho 2\pi R^3 V_T^2}$$

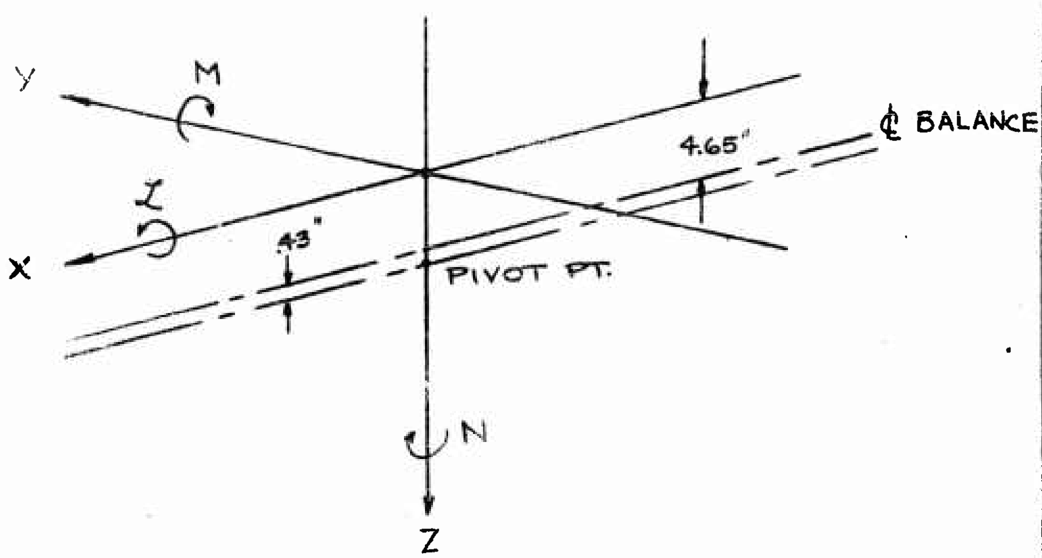
$$C_L = \frac{L}{qS}$$

REV

$$C_D = \frac{D}{qS}$$

General

C	Tunnel test section cross sectional area, sq. ft.
C_G	Ground board test section area, sq. ft.
q	Dynamic pressure = $1/2\rho V^2$, lbs. per sq. ft.
R	Model rotor radius, ft.
	Swept rotor area (twice the area swept by one rotor)
V	Tunnel velocity, ft. per sec.
V_T	Rotor tip speed, ft. per sec.
α	Angle of attack, degrees, positive nose up.
ψ	Angle of yaw, degrees, positive nose right.
δ	Tunnel wall correction factor.
ρ	Density, slugs per cu. ft.



REV

UNIVERSITY OF MARYLAND WIND TUNNEL OPERATIONS DEPARTMENT
PROGRAM OF WIND TUNNEL TESTS

MODEL RANGE EXTENSION STUDY TEST NO. 278 DATE MARCH 1960

	RUN NO.	VAR. NO.	γ	CONFIGURATION		VERTOL RUNS	C.P. NO.	δ_F	REMARKS
3/15	1	1	Variable	Helicopter		1-18	1		6C
	2					19-26	2		
	3					27-40	3		
	4					41-48	4		
3/16	5	2			+ Wooden Wing	49-50	1		
	6					49-71	1		
	7					72-79	2		
	8					80-98	3		
	9					99-106	4		
	10					149-151	3		Wing Dynamics
3/17	11	3			+ Metal Wing	114-120	1		6C
	12					124-126	2		
	13					134-140	3		
	14					144-146	4		
3/18	15								Pitot Tube Rdgs.
	16								Pitot Tube Rdgs. with Ground Board Installed
3/21	17				+ G.B.	159-161	1		6C
	18								Photos Only

UNIVERSITY OF MARYLAND WIND TUNNEL OPERATIONS DEPARTMENT
PROGRAM OF WIND TUNNEL TESTS

MODEL RANGE EXTENSION STUDY TEST NO. 278 DATE MARCH 1960

	RUN NO.	VAR. NO.	γ	CONFIGURATION	VERTOL RUNS	C.P. NO.	REMARKS
3/22	19	—	3.05	Helicopter + Wood Wing + G.B.	157-158	1	6C, Rt. Wing Jammed
	20	—			157-158	1	6C
	21	4	Var.	Helicopter + G.B.	152-156		6C
	22		24.6	+ Metal Wing	148		Wing Dynamics
	23				165		Wing Jettison Test
	24				165		
	25			+ Wood Wing	162		No Rotors
3/23	26		16.6		164		
	27				164		

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

WIND TUNNEL PROGRAM

RUN NO.	CONFIGURATION WING None	Wood	Metal	COLLECTIVE PITCH SET NO. 1	2	3	4	TUNNEL SPEED Kts	q	MODEL ANGLE OF ATTACK α Deg.	YAW ANGLE Deg.	WING ATTITUDE Deg.	FLAP ANGLE Deg.	PURPOSE
1	X			X				30	3.05	1	0			Helicopter Power & Stability Information
2	X			X				30	3.05	-1	0			
3	X			X				40	5.43	1	0			
4	X			X				40	5.43	-1	0			
5	X			X				70	16.6	-5	0			
6	X			X				70	16.6	-8	0			
7	X			X				70	16.6	-11	0			
8	X			X				80	21.7	-8	0			
9	X			X				80	21.7	-11	0			
10	X			X				85	24.6	-9	0			
11	X			X				85	24.6	-12	0			
12	X			X				85	24.6	-15	0			
13	X			X				90	27.5	-12	0			
14	X			X				90	27.5	-15	0			
15	X			X				85	24.6	-9	5			Yaw Stability Derivatives
16	X			X				85	24.6	-15	5			
17	X			X				85	24.6	-15	10			
18	X			X				85	24.6	-9	10			
19	X				X			30	3.05	1	0			
20	X				X			30	3.05	-1	0			
21	X				X			70	16.6	-5	0			
22	X				X			70	16.6	-8	0			
23	X				X			70	16.6	-11	0			
24	X				X			85	24.6	-9	0			
25	X				X			85	24.6	-12	0			
26	X				X			85	24.6	-15	0			
27	X					X		30	3.05	1	0			Helicopter Power & Stability Information
28	X					X		30	3.05	-1	0			
29	X					X		40	5.43	1	0			
30	X					X		40	5.43	-1	0			
31	X					X		70	16.6	-5	0			
32	X					X		70	16.6	-8	0			
33	X					X		70	16.6	-11	0			
34	X					X		80	21.7	-8	0			
35	X					X		80	21.7	-11	0			
36	X					X		85	24.6	-9	0			
37	X					X		85	24.6	-12	0			
38	X					X		85	24.6	-15	0			
39	X					X		90	27.5	-12	0			
40	X					X		90	27.5	-15	0			
41	X						X	30	3.05	1	0			
42	X						X	30	3.05	-1	0			
43	X						X	70	16.6	-5	0			
44	X						X	70	16.6	-8	0			
45	X						X	70	16.6	-11	0			
46	X						X	85	24.6	9	0			
47	X						X	85	24.6	-12	0			
48	X						X	85	24.6	-15	0			
49		X		X				30	3.05	1	0	0	-	Low Wing Loading Power & Stability Information
50		X		X				30	3.05	-1	0	-	(49)	
51		X		X				30	3.05	-1	0	0	-	
52		X		X				40	5.43	1	0	-	(49)	
53		X		X				40	5.43	-1	0	-	(51)	
54		X		X				70	16.6	-5	0	0	-	
55		X		X				70	16.6	-8	0	-	(54)	
56		X		X				70	16.6	-8	0	0	-	
57		X		X				70	16.6	-11	0	-	(56)	
58		X		X				70	16.6	-11	0	0	-	
59		X		X				80	21.7	-8	0	-	(56)	
60		X		X				80	21.7	-11	0	-	(58)	
61		X		X				85	24.6	-9	0	0	-	
62		X		X				85	24.6	-12	0	-	(61)	
63		X		X				85	24.6	-12	0	0	-	
64		X		X				85	24.6	-15	0	-	(63)	
65		X		X				85	24.6	-15	0	0	-	

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

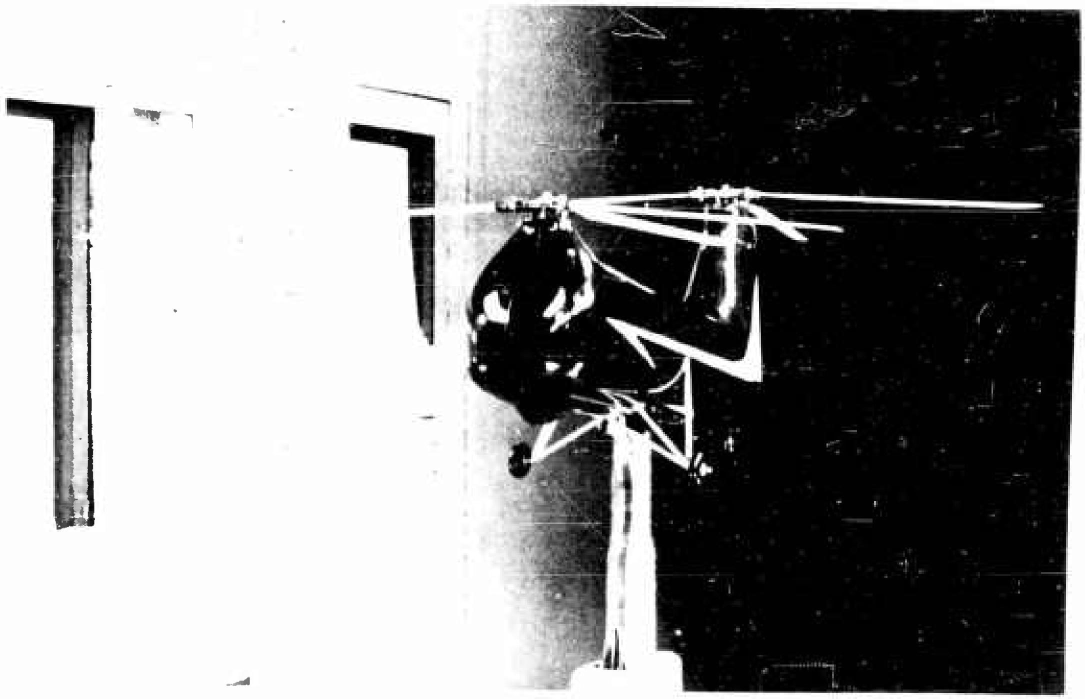
WIND TUNNEL PROGRAM

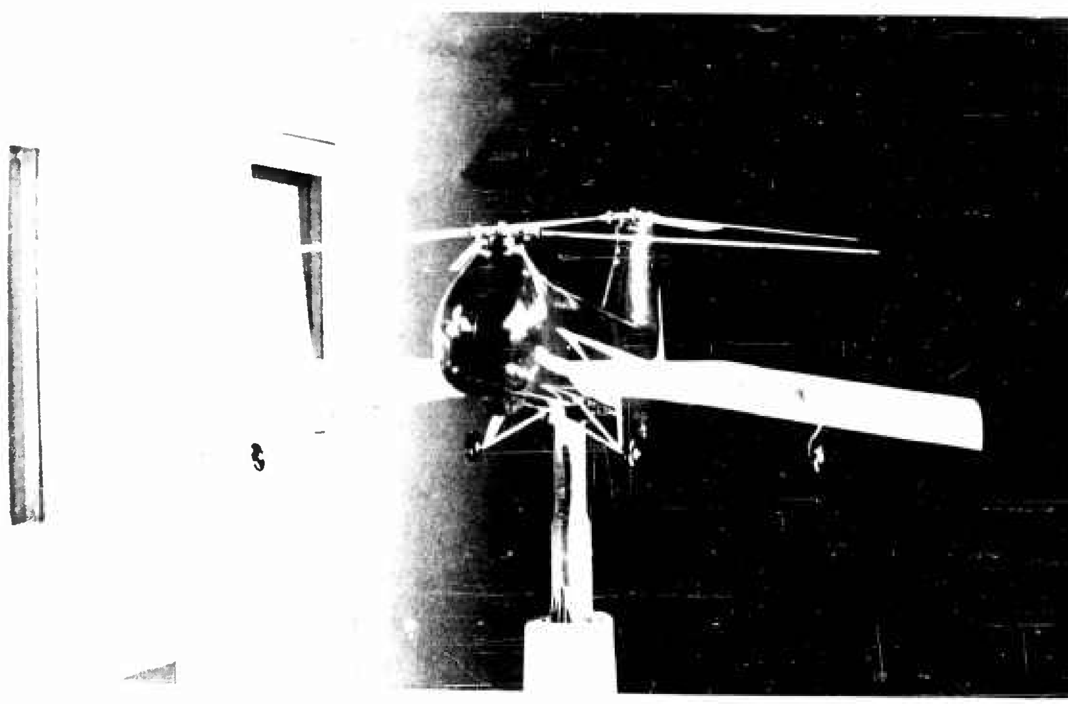
RUN NO.	CONFIGURATION WING None	Wood	Metal	COLLECTIVE PITCH SET NO. 1	2	3	4	TUNNEL SPEED Kts	q	MODEL ANGLE OF ATTACK α_F Deg.	YAW ANGLE Deg.	WING ATTITUDE Deg.	FLAP ANGLE Deg.	PURPOSE
66		X		X				90	27.5	-12	0	-	(63)	Yaw Stabil-ity Deriva-tives
67		X		X				90	27.5	-15	0	-	(65)	
68		X		X				85	24.6	-9	5	-	(61)	
69		X		X				85	24.6	-15	5	-	(65)	
70		X		X				85	24.6	-15	10	-	(65)	
71		X		X				85	24.6	-9	10	-	(61)	
72		X			X			30	3.05	1	0	0	-	
73		X			X			30	3.05	-1	0	0	-	
74		X			X			70	16.6	-5	0	0	-	
75		X			X			70	16.6	-8	0	0	-	
76		X			X			70	16.6	-11	0	0	-	
77		X			X			85	24.6	-9	0	0	-	
78		X			X			85	24.6	-12	0	0	-	
79		X			X			85	24.6	-15	0	0	-	
80		X				X		30	3.05	1	0	0	-	
81		X				X		30	3.05	-1	0	-	(80)	
82		X				X		30	3.05	-1	0	0	-	
83		X				X		40	5.43	1	0	-	(80)	Low Wing Loading Power & Stability Information
84		X				X		40	5.43	-1	0	-	(82)	
85		X				X		70	16.6	-5	0	0	-	
86		X				X		70	16.6	-8	0	-	85	
87		X				X		70	16.6	-8	0	0	-	
88		X				X		70	16.6	-11	0	-	(87)	
89		X				X		70	16.6	-11	0	0	-	
90		X				X		80	21.7	-8	0	-	(87)	
91		X				X		80	21.7	-11	0	-	(89)	
92		X				X		85	24.6	-9	0	0	-	
93		X				X		85	24.6	-12	0	-	(92)	
94		X				X		85	24.6	-12	0	0	-	
95		X				X		85	24.6	-15	0	-	(94)	
96		X				X		85	24.6	-15	0	0	-	
97		X				X		90	27.5	-12	0	-	(94)	
98		X				X		90	27.5	-15	0	-	(96)	
99		X					X	30	3.05	1	0	0	-	
100		X					X	30	3.05	-1	0	0	-	
101		X					X	70	16.6	-5	0	0	-	
102		X					X	70	16.6	-8	0	0	-	
103		X					X	70	16.6	-11	0	0	-	
104		X					X	85	24.6	-9	0	0	-	
105		X					X	85	24.6	-12	0	0	-	
106		X					X	85	24.6	-15	0	0	-	
107			X	X				70	16.6	-5	0	0	-	
108			X	X				70	16.6	-8	0	-	(102)	
109			X	X				70	16.6	-8	0	0	-	
110			X	X				70	16.6	-11	0	-	(109)	
111			X	X				70	16.6	-11	0	0	-	High Wing Loading Power & Stability Information
112			X	X				80	21.7	-8	0	-	(109)	
113			X	X				80	21.7	-11	0	-	(111)	
114			X	X				85	24.6	-9	0	0	-	
115			X	X				85	24.6	-12	0	-	(114)	
116			X	X				85	24.6	-12	0	0	-	
117			X	X				85	24.6	-15	0	-	(116)	
118			X	X				85	24.6	-15	0	0	-	
119			X	X				90	27.5	-12	0	-	(116)	
120			X	X				90	27.5	-15	0	-	(118)	
121			X		X			70	16.6	-5	0	0	-	
122			X		X			70	16.6	-8	0	0	-	
123			X		X			70	16.6	-11	0	0	-	
124			X		X			85	24.6	-9	0	0	-	
125			X		X			85	24.6	-12	0	0	-	
126			X		X			85	24.6	-15	0	0	-	
127			X			X		70	16.6	-5	0	0	-	
128			X			X		70	16.6	-8	0	-	(127)	
129			X			X		70	16.6	-8	0	0	-	
130			X			X		70	16.6	-11	0	-	(129)	

HELICOPTER RANGE EXTENSION WIND TUNNEL STUDY

WIND TUNNEL PROGRAM

RUN NO.	CONFIGURATION WING None	Wood	Metal	COLLECTIVE PITCH SET NO. 1	2	3	4	TUNNEL SPEED Kts	q	MODEL ANGLE OF ATTACK α_F Deg.	YAW ANGLE Deg.	WING ATTITUDE Deg.	FLAP ANGLE Deg.	PURPOSE
131			X			X		70	16.6	-11	0	0	-	High Wing Loading Power & Stability Information
132			X			X		80	21.7	-8	0	-	(129)	
133			X			X		80	21.7	-11	0	-	(131)	
134			X			X		85	24.6	-9	0	0	-	
135			X			X		85	24.6	-12	0	-	(134)	
136			X			X		85	24.6	-12	0	0	-	
137			X			X		85	24.6	-15	0	-	(136)	
138			X			X		85	24.6	-15	0	0	-	
139			X			X		90	27.5	-12	0	-	(136)	
140			X			X		90	27.5	-15	0	-	(138)	
141			X				X	70	16.6	-5	0	0	-	
142			X				X	70	16.6	-8	0	0	-	
143			X				X	70	16.6	-11	0	0	-	
144			X				X	85	24.6	-9	0	0	-	
145			X				X	85	24.6	-12	0	0	-	
146			X				X	85	24.6	-15	0	0	-	
147			X	X				70	16.6	-8	0	f(t)	(109)	
148			X	X				85	24.6	-12	0	f(t)	(116)	Wing Dynamics
149		X		X				30	3.05	-1	0	f(t)	(51)	
150		X		X				70	16.6	-8	0	f(t)	(56)	
151		X		X				85	24.6	-12	0	f(t)	(63)	
152	X			X				30	3.05	+1	0			
153	X			X				30	3.05	-1	0			
154	X			X				70	16.6	-5	0			In-Ground Effect
155	X			X				70	16.6	-8	0			
156	X			X				70	16.6	-11	0			
157		X		X				30	3.05	1	0	0	-	
158		X		X				30	3.05	-1	0	0	-	
159			X	X				70	16.6	-5	0	0	-	
160			X	X				70	16.6	-8	0	0	-	
161			X	X				70	16.6	-11	0	0	-	
162		X						70	16.6	-8	0	0	-	
163			X					70	16.6	-8	0	0	-	Jettison Test
164		X		X				70	16.6	-8	0	0	-	
165			X	X				70	16.6	-8	0	0	-	





[illegible] with Wood Wing

Fig. [illegible]

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Model Vertol Range Extension Study Test No. 278

Run No. 1 q = ✓ Model Configuration Helicopter ~ CP1

Vertol Run No.	q (psf)	α	$\psi°$	$C_z \times 10^4$	$C_x \times 10^4$	$C_m \times 10^4$	$C_n \times 10^4$	$C_\ell \times 10^4$	$C_y \times 10^4$	Input Power (Watts)
1	3.05	2.4	0	-33.53	- 3.11	4.58	- .16	- .18	- .68	3520
2	3.05	.4	0	-33.53	- 2.05	3.81	- .09	- .25	- .50	3560
3	5.43	1.9	0	-37.57	- 3.83	5.17	- .07	- .28	- .50	3440
4	5.43	- .1	0	-36.95	- 2.54	4.09	- .03	- .23	- .75	3520
5	16.60	-4.7	0	-38.50	- 2.93	1.53	.18	.12	- .93	3584
6	16.60	-7.7	0	-33.22	- 1.11	.88	.15	.16	- .81	3640
7	16.60	-10.8	0	-27.01	- .07	.51	.17	- .14	- .93	3624
8	21.70	- 7.8	0	-32.60	- 2.56	.41	.20	.23	-1.18	3600
9	21.70	-10.9	0	-25.46	- 1.65	- .12	.21	.24	-1.24	3600
10	24.60	- 8.8	0	-29.50	- 2.94	0	.24	.26	-1.30	3616
11	24.60	-11.9	0	-21.74	- 2.31	- .47	.22	.27	-1.37	3536
12	24.60	-14.9	0	-12.73	- 2.93	- .70	.20	.25	-1.30	3080
13	27.50	-11.9	0	-20.49	- 3.20	- .56	.23	.33	-1.55	3440
14	27.50	-14.9	0	-10.87	- 4.05	- .84	.21	.36	-1.68	2960
15	24.60	- 8.9	5	-29.19	- 3.00	.48	.39	.37	1.30	3608
16	24.60	-14.9	5	-12.42	- 3.12	- .02	.32	.63	.87	3056
17	24.60	-14.9	10	-12.11	- 3.61	.20	.09	.56	4.66	3064
18	24.60	- 8.8	10	-29.50	- 3.53	.76	.33	.52	4.72	3640
12	24.60	-14.9	0	-13.35	2.97	.07	.23	.34	-1.43	3080

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Model Vertol Range Extension Study Test No. 278

Run No. 2 q = ✓ Model Configuration Helicopter — CP2

Vertol Run No.	q (psf)	$\alpha°$	$\psi°$	$C_z \times 10^4$	$C_x \times 10^4$	$C_m \times 10^4$	$C_n \times 10^4$	$C_\ell \times 10^4$	$C_y \times 10^4$	Input Power (Watts)
19	3.05	2.6	0	-39.74	-4.12	11.45	-1.15	- .52	-1.06	4400
20	3.05	.6	0	-38.50	-2.59	10.52	-1.05	- .48	-1.24	4400
21	16.60	-4.7	0	-44.40	-3.27	9.09	- .68	0	-1.30	4560
22	16.60	-7.7	0	-40.05	-1.24	8.37	- .69	.02	-1.24	4560
23	16.60	-10.7	0	-34.78	.55	8.43	- .68	.14	-1.24	4520
24	24.60	- 8.8	0	-38.19	-2.96	7.81	- .59	.22	-1.61	4520
25	24.60	-11.8	0	-30.43	-1.57	7.74	- .60	.21	-1.61	4360
26	24.60	-14.9	0	-21.74	-1.50	7.91	- .78	.32	-1.49	4000

UNIVERSITY OF MARYLAND AERONAUTICAL LABORATORY

Model Vertol Range Extension Study Test No. 278

Run No. 3 q = ______ Model Configuration Helicopter CP3

Vertol Run No.	q (psf)	$\alpha°$	$\psi°$	$C_z \times 10^4$	$C_x \times 10^4$	$C_m \times 10^4$	$C_n \times 10^4$	$C_\ell \times 10^4$	$C_y \times 10^4$	Input Power (Watts)
27	3.05	3.0	0	-49.37	-5.14	4.93	- .48	- .20	-1.06	5760
28	3.05	1.0	0	-49.37	-3.56	4.18	- .45	- .20	-1.06	5800
29	5.43	2.2	0	-53.41	-5.69	5.61	- .51	- .19	- .93	5680
30	5.43	.2	0	-53.41	-3.92	4.58	- .45	- .18	- .99	5760
31	16.60	-4.6	0	-55.58	-3.70	2.34	- .17	.27	- .87	5640
32	16.60	-7.6	0	-52.47	- .87	1.47	- .16	.28	- .93	5760
33	16.60	-10.6	0	-47.20	1.53	1.05	.01	.29	- .99	5800
34	21.70	- 7.7	0	-51.23	-2.48	1.26	- .16	.28	- .93	5760
35	21.70	-10.7	0	-46.58	- .06	.59	- .01	.41	-1.43	5768
36	24.60	- 8.7	0	-49.06	-2.64	.75	- .09	.40	-1.24	5800
37	24.60	-11.8	0	-44.09	- .39	.03	.02	.40	-1.24	5840
38	24.60	-14.8	0	-35.09	.92	- .25	.07	.41	-1.30	5800
39	27.50	-11.8	0	-42.54	-1.26	.03	.02	.41	-1.30	5840
40	27.50	-14.8	0	-35.09	- .04	- .66	.10	.42	-1.37	5800

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Model Vertol Range Extension Study Test No. 278

Run No. 4 q = ∪ Model Configuration Helicopter — CP4

Vertol Run No.	q (psf)	α	$\psi°$	$C_z \times 10^4$	$C_x \times 10^4$	$C_m \times 10^4$	$C_n \times 10^4$	$C_\ell \times 10^4$	$C_y \times 10^4$	Input Power (Watts)
41	3.05	2.8	0	-43.78	-4.39	- .28	.35	- .04	- .62	4640
42	3.05	.8	0	-43.78	-2.84	-1.98	.38	.01	- .56	4720
43	16.60	- 4.6	0	-48.44	-3.23	-3.89	.55	.33	- .37	4600
44	16.60	- 7.7	0	-43.47	- .84	-5.35	.55	.34	- .43	4680
45	16.60	-10.7	0	-37.88	+ .93	-6.26	.64	.32	- .81	4728
46	24.60	- 8.8	0	-40.68	-2.67	-6.09	.61	.47	-1.06	4680
47	24.60	-11.8	0	-33.84	-1.09	-7.38	.66	.45	-1.18	4640
48	24.60	-14.9	0	-26.39	- .71	-8.60	.79	.35	- .99	4440

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Model Vertol Range Extension Study Test No. 278

Run No. 5 q = U Model Configuration Helicopter + Wooden Wings ~ CP1

Vertol Run No.	q (psf)	α	ψ	$C_{[illegible]} \times 10^4$	$C_x \times 10^4$	$C_m \times 10^4$	$C_n \times 10^4$	$C_\ell \times 10^4$	$C_y \times 10^4$	Input Power (Watts)
49	3.05	2.6	0	-38.50	-4.73	5.63	-.13	.12	-.75	3600
50	3.05	.6	0	-37.26	-3.36	.96	0	.15	-.75	3584

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Model Vertol Range Extension Study Test No. 278

Run No. 6 q = ✓ Model Configuration Helicopter + Wooden Wings CP1

Vertol Run No.	q (psf)	α	$\psi°$	$C_z \times 10^4$	$C_x \times 10^4$	$C_m \times 10^4$	$C_n \times 10^4$	$C_\ell \times 10^4$	$C_y \times 10^4$	Input Power (Watts)
49	3.05	2.5	0	-37.26	- 4.51	5.50	- .13	.04	- .50	3600
50	3.05	.5	0	-36.33	- 3.16	5.04	- .10	- .03	- .37	3584
51	3.05	.5	0	-36.33	- 3.09	5.12	- .22	.04	- .68	3584
52	5.43	2.0	0	-41.92	- 4.96	6.65	- .19	.08	- .68	3480
53	5.43	- .1	0	-40.68	- 3.62	5.67	- .19	.05	- .75	3560
54	16.60	-4.6	0	-47.82	- 5.05	7.34	.24	.15	-1.24	3600
55	16.60	-7.7	0	-44.40	- 2.93	6.71	- .01	.01	- .56	3664
56	16.60	-7.7	0	-43.47	- 2.67	6.19	.09	0	- .50	3680
57	16.60	-10.7	0	-36.95	- 1.45	5.78	.05	0	- .50	3680
58	16.60	-10.7	0	-36.33	- 1.11	5.33	- .01	.01	- .56	3680
59	21.70	- 7.7	0	-45.33	- 4.31	7.23	.12	.02	- .62	3664
60	21.70	-10.8	0	-36.02	- 2.77	5.33	- .07	.03	- .68	3640
61	24.60	- 8.8	0	-43.78	- 4.92	7.52	.05	.05	- .75	3608
62	24.60	-11.8	0	-34.47	- 4.15	6.42	.04	.07	- .87	3440
63	24.60	-11.8	0	-32.91	- 3.67	5.72	- .03	.05	- .75	3440
64	24.60	-14.9	0	-22.98	- 3.96	4.63	- .06	.07	- .68	3000
65	24.60	-14.9	0	-19.87	- 4.05	3.50	- .09	.10	- .81	2960
66	27.50	-11.8	0	-33.84	- 4.50	5.81	- .02	.13	- .99	3400
67	27.50	-14.9	0	-30.74	- 4.30	5.28	- .12	.08	- .73	3424
68	24.60	- 8.8	5	-43.78	- 5.11	8.36	.16	- .40	2.42	3600
69	24.60	-14.9	5	-21.42	- 4.11	3.83	.01	- .42	2.24	3024
70	24.60	-14.9	10	-21.42	- 4.64	4.18	- .31	-1.14	6.52	3024
71	24.60	- 8.8	10	-43.16	- 5.73	7.83	.11	-1.04	6.09	3600

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Model Vertol Range Extension Study Test No. 278

Run No. 7 q = √ Model Configuration Helicopter + Wooden Wing ~ CP2

Vertol Run No.	q (psf)	α	ψ°	$C_z \times 10^4$	$C_x \times 10^4$	$C_m \times 10^4$	$C_n \times 10^4$	$C_\ell \times 10^4$	$C_y \times 10^4$	Input Power (Watts)
72	3.05	2.7	0	-41.92	-5.12	11.45	- .93	.15	- .75	4360
73	3.05	.7	0	-41.92	-3.97	10.95	- .83	.24	-1.18	4400
74	16.60	-4.6	0	-55.58	-5.56	14.86	- .50	.12	- .62	4360
75	16.60	-7.6	0	-49.06	-2.68	13.07	- .46	.12	- .62	4384
76	16.60	-10.7	0	-42.23	- .61	11.66	- .59	.12	- .62	4376
77	24.60	- 8.7	0	-50.61	-5.26	14.55	- .43	.01	- .56	4336
78	24.60	-11.8	0	-40.99	-3.22	12.61	- .60	.16	- .81	4160
79	24.60	-14.8	0	-29.50	-2.63	10.83	- .72	.06	- .81	3904

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Model Vertol Range Extension Study Test No. 278

Run No. 8 q = U Model Configuration Helicopter + Wooden Wings — CP3

Vertol Run No.	q (psf)	α	$\psi°$	$C_z \times 10^4$	$C_x \times 10^4$	$C_m \times 10^4$	$C_n \times 10^4$	$C_\ell \times 10^4$	$C_y \times 10^4$	Input Power (Watts)
80	3.05	3.0	0	-48.75	- 5.88	8.09	- .67	.19	- .93	4960
81	3.05	1.0	0	-47.20	- 4.16	7.17	- .51	.24	-1.18	5000
82	3.05	1.0	0	-47.20	- 4.22	7.29	- .57	.22	-1.12	5000
83	5.43	2.2	0	-52.79	- 6.35	8.63	- .70	.22	-1.12	4960
84	5.43	.2	0	-51.85	- 4.88	8.11	- .61	.24	-1.18	5000
85	16.60	-4.5	0	-62.41	- 5.52	10.99	- .30	.20	- .99	5000
86	16.60	-7.6	0	-57.13	- 3.07	9.46	- .20	.16	- .81	5000
87	16.60	-7.6	0	-56.51	- 2.50	9.17	- .17	.15	- .62	5072
88	16.60	-10.6	0	-50.61	- .49	7.85	- .11	.14	- .56	5040
89	16.60	-10.6	0	-49.06	- .16	7.46	- .26	.19	- .81	5024
90	21.70	- 7.7	0	-57.75	- 4.19	9.58	- .11	.18	- .75	5040
91	21.70	-10.7	0	-50.61	- 1.84	7.86	- .26	.12	- .62	5000
92	24.60	- 8.7	0	-59.00	- 5.25	10.45	- .17	.13	- .68	4960
93	24.60	-11.7	0	-50.61	- 3.21	9.32	- .08	.18	- .93	4880
94	24.60	-11.7	0	-48.75	- 2.42	8.08	- .18	.17	- .87	4920
95	24.60	-14.8	0	-39.43	- 1.44	6.84	- .18	.13	- .68	4760
96	24.60	-14.8	0	-37.88	- 1.16	5.80	- .28	.13	- .68	4760
97	27.50	-11.8	0	-48.75	- 3.33	8.28	- .15	.17	- .87	4880
98	27.50	-14.8	0	-36.33	- 2.19	5.92	- .27	.16	- .81	4744

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Model Vertol Range Extension Study Test No. 278

Run No. 9 q = ✓ Model Configuration Helicopter + Wooden Wings ~ CP4

Vertol Run No.	q (psf)	α	$\psi°$	$C_z \times 10^4$	$C_x \times 10^4$	$C_m \times 10^4$	$C_n \times 10^4$	$C_\ell \times 10^4$	$C_y \times 10^4$	Input Power (Watts)
99	3.05	2.8	0	-43.47	-5.18	2.21	.29	.17	- .68	4120
100	3.05	.8	0	-42.54	-3.76	1.68	.19	.19	- .81	4144
101	16.60	-4.6	0	-54.96	-5.68	3.33	.56	.28	-1.43	4000
102	16.60	-7.6	0	-49.37	-2.49	2.48	.37	.18	- .75	4160
103	16.60	-10.7	0	-41.61	- .48	.74	.35	.13	- .68	4200
104	24.60	-8.7	0	-50.92	-4.86	3.70	.41	.15	- .75	4144
105	24.60	-11.8	0	-39.74	-2.81	1.00	.36	.16	- .81	4040
106	24.60	-14.9	0	-27.63	-2.55	-1.52	.43	.17	- .87	3760

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Model Vertol Range Extension Study Test No. 278

Run No. 11 q = ✓ Model Configuration Helicopter + Metal Wings — CP1

Vertol Run No.	q (psf)	$\alpha°$	$\psi°$	$C_z \times 10^4$	$C_x \times 10^4$	$C_m \times 10^4$	$C_n \times 10^4$	$C_\ell \times 10^4$	$C_y \times 10^4$	Input Power (Watts)
114	24.60	-8.7	0	-65.52	-8.86	14.86	-.11	-.11	.43	3560
115	24.60	-11.7	0	-56.20	-7.89	13.80	-.12	-.07	.37	3424
116	24.60	-11.7	0	-55.58	-8.79	13.34	.02	-.10	.19	3400
117	24.60	-14.8	0	-44.40	-9.28	11.51	-.05	-.02	.43	2880
118	24.60	-14.8	0	-44.09	-9.36	11.89	-.16	-.12	.62	2880
119	27.50	-11.8	0	-53.10	-9.73	12.78	.08	.18	.43	3280
120	27.50	-14.8	0	-42.85	-10.52	11.52	-.18	.20	.87	2800

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Model Vertol Range Extension Study Test No. 278

Run No. 12 q = ✓ Model Configuration Helicopter + Metal Wing ~ CP2

Vertol Run No.	q (psf)	α	$\psi°$	$C_z \times 10^4$	$C_x \times 10^4$	$C_m \times 10^4$	$C_n \times 10^4$	$C_\ell \times 10^4$	$C_y \times 10^4$	Input Power (Watts)
124	24.60	- 8.6	0	-70.17	- 9.01	19.56	- .43	- .25	.62	4040
125	24.60	-11.7	0	-61.48	- 8.35	18.44	- .82	- .23	1.18	3344
126	24.60	-14.7	0	-50.92	- 8.83	17.01	- .76	.01	.62	3520

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Model Vertol Range Extension Study Test No. 278

Run No. 13 q = ✓ Model Configuration Helicopter + Metal Wings CP3

Vertol Run No.	q (psf)	α	$\psi°$	$C_z \times 10^4$	$C_x \times 10^4$	$C_m \times 10^4$	$C_n \times 10^4$	$C_\ell \times 10^4$	$C_y \times 10^4$	Input Power (Watts)
134	24.60	- 8.6	0	-81.35	- 8.79	12.07	.30	- .12	.75	5160
135	24.60	-11.6	0	-73.28	- 6.38	9.73	.29	- .10	.68	5240
136	24.60	-11.6	0	-73.28	- 7.31	9.48	.27	- .04	.37	5280
137	24.60	-14.7	0	-63.96	- 5.96	7.55	.26	- .08	.56	5184
138	24.60	-14.7	0	-63.65	- 6.04	7.58	.22	- .10	.68	5160
140	27.50	-14.7	0	-62.10	- 7.02	7.21	.22	- .13	.81	5120
139	27.50	-11.7	0	-72.35	- 8.43	9.10	.24	- .07	.50	5240

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Model Vertol Range Extension Study Test No. 278

Run No. 14 q = $\checkmark$ Model Configuration Helicopter + Metal Wings ~ CP4

Vertol Run No.	q (psf)	α	ψ	$C_z \times 10^4$	$C_x \times 10^4$	$C_m \times 10^4$	$C_n \times 10^4$	$C_\ell \times 10^4$	$C_y \times 10^4$	Input Power (Watts)
144	24.60	- 8.6	0	-75.76	- 8.34	8.10	.74	- .15	.93	4680
145	24.60	-11.7	0	-66.76	- 6.73	5.25	.46	.02	.56	4640
146	24.60	-14.7	0	-57.13	- 7.21	3.01	.58	- .05	.56	4320

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Model Vertol Range Extension Study Test No. 278

Run No. 17 q = J Model Configuration Helicopter + Metal Wing + GB ~ CP1

Vertol Run No.	q (psf)	α	ψ	$C_z \times 10^4$	$C_x \times 10^4$	$C_m \times 10^4$	$C_n \times 10^4$	$C_\ell \times 10^4$	$C_y \times 10^4$	Input Power (Watts)
159	24.60	- 8.9	0	-84.77	- 7.73	11.78	.22	.15	.06	5040
160	24.60	-11.9	0	-75.45	- 6.12	9.10	.40	.02	.19	5160
161	24.60	-14.9	0	-65.52	- 5.22	7.03	.07	.24	- .12	5000

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Model Vertol Range Extension Study Test No. 278

Run No. 20 q = 0 Model Configuration Helicopter + Wood Wing + GB — CP1

Vertol Run No.	q (psf)	α	$\psi°$	$C_z \times 10^4$	$C_x \times 10^4$	$C_m \times 10^4$	$C_n \times 10^4$	$C_\ell \times 10^4$	$C_y \times 10^4$	Input Power (Watts)
157	3.05	1.4	0	-51.54	- 4.75	2.86	0	- .28	- .50	5080
158	3.05	- .6	0	-50.92	- 3.19	1.26	.22	- .13	- .31	5160
158	3.05	- .6	0	-51.85	- 3.04	1.80	- .03	- .22	- .37	5160
157	3.05	1.4	0	-51.85	- 4.59	3.02	- .10	- .18	- .56	5080

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Model Vertol Range Extension Study Test No. 278

Run No. 21 q = ✓ Model Configuration Helicopter + G.B. — CP1

Vertol Run No.	q (psf)	α	$\psi°$	$C_z \times 10^4$	$C_x \times 10^4$	$C_m \times 10^4$	$C_n \times 10^4$	$C_\ell \times 10^4$	$C_y \times 10^4$	Input Power (Watts)
152	3.05	1.4	0	-48.13	- 3.83	1.43	0	- .15	- .68	5120
153	3.05	- .6	0	-48.13	- 2.06	.47	.06	- .28	- .37	5160
154	16.60	-4.9	0	-52.47	- 3.77	- .65	.32	.05	.06	4960
155	16.60	-7.9	0	-47.51	- 1.18	-1.76	.32	.08	- .12	5040
156	16.60	-10.9	0	-42.85	.85	-2.75	.27	.11	- .25	5120